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TECHNICAL BULLETIN

# EVALUATION OF LAND APPLICATION SYSTEMS

MARCH 1975

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Water Program Operations
Washington, D.C. 20460

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U.S. DEPARTMENT OF COMMERCE
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## NOTES

To order this publication, MCD-07, Technical Bulletin, Evaluation of Land Application Systems, March 1975.

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| | | | |
|---|---|---|---|
| **BIBLIOGRAPHIC DATA SHEET** | 1. Report No.<br>EPA-430/9-75-001 MCD-07 | 2. | 3. Recipient's Accession No. |

4. Title and Subtitle

Evaluation of Land Application Systems

5. Report Date
March 1975

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Environmental Protection Agency
Office of Water Program Operations
401 M Street, SW
Washington, D.C.

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

This technical bulletin is published pursuant to certain sections of the Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, enacted on October 18, 1972. The 1972 Amendments require the publication of information that will encourage waste treatment management which results in facilities for (1) the recycling of potential sewage pollutants through the production of agricultural, silvicultural, or aquacultural products; (2) the reclamation of wastewater; and (3) the elimination of the discharge of pollutants. The Amendments also require the consideration of alternative waste management techniques that provide the best practicable waste treatment technology over the life of the treatment works.

17. Key Words and Document Analysis. 17a. Descriptors

Wastewater Management Plan
Operation and Maintenance
Land Application

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

| | | |
|---|---|---|
| 18. Availability Statement | 19. Security Class (This Report)<br>UNCLASSIFIED | 21. No. of Pages<br>190 |
| | 20. Security Class (This Page)<br>UNCLASSIFIED | 22. Price<br>7.50 |

FORM NTIS-35 (REV. 3-72) USCOMM-DC 14952-P72

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EPA-430/9-75-001

TECHNICAL BULLETIN

# EVALUATION OF LAND APPLICATION SYSTEMS

## EVALUATION CHECKLIST AND SUPPORTING COMMENTARY

MARCH 1975

SECOND PRINTING -- APRIL 1976

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Water Program Operations
Washington, D.C. 20460

MCD-07

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# ABSTRACT

Procedures are set forth to assist EPA personnel in evaluating treatment systems that employ land application of municipal wastewater. In addition, information and assistance is provided which may be of value to other federal, state, and local agencies, the wastewater industry, consultants and designers. However, it is not intended that the bulletin be used as a comprehensive design manual.

The bulletin consists of an Evaluation Checklist and parallel background information and is divided into three major parts dealing with: (1) facilities plans, (2) design plans and specifications, and (3) operation and maintenance manuals.

The focus of Part I is on the thorough evaluation of land-application alternatives and the preparation of a detailed facilities plan. A number of interrelated considerations are addressed, including: evaluation of potential sites, evaluation of land-application alternatives, design considerations, and environmental factors.

Procedures for evaluating design plans and specifications are described in Part II, with emphasis being placed on agreement with the facilities plans and the requirement for basing the review of the design on conditions present at the particular site. Sample design criteria listings are included in the appendix.

In Part III, extensive reference is made to the EPA publication Considerations for Preparation of Operation and Maintenance Manuals. Special considerations for land-application systems are presented with respect to operating procedures, monitoring requirements, and impact control.

This report is submitted in partial fulfillment of Contract 68-01-0966 by Metcalf & Eddy, Inc., Western Regional Office, under the sponsorship of the Environmental Protection Agency. Work was completed as of September 1974.

**TECHNICAL BULLETIN** **EPA-430/9-75-001**

## FOREWORD

This technical bulletin is published pursuant to certain sections of the Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, enacted on October 18, 1972. The 1972 Amendments require the publication of information that will encourage waste treatment management which results in facilities for (1) the recycling of potential sewage pollutants through the production of agricultural, silvicultural, or aquacultural products; (2) the reclamation of wastewater; and (3) the elimination of the discharge of pollutants. The Amendments also require the consideration of alternative waste management techniques that provide the best practicable waste treatment technology over the life of the treatment works.

The three principal waste management alternatives are (1) conventional treatment and discharge, (2) conventional treatment and direct reuse, and (3) land treatment with discharges to surface and/or groundwaters. Treatment by land application of wastewater is a viable waste management alternative and is practiced successfully and extensively both in the United States and throughout the world. This publication is concerned solely with land application for wastewater treatment and is intended to encourage its use where it is cost-effective.

This bulletin is not a comprehensive design manual; primarily, it provides information and program guidance to EPA Regional Offices for analyzing and evaluating municipal applications for federal grants for the construction of publicly owned treatment works using land-application methods. It also provides information and assistance to other federal agencies, to interstate organizations, to state water pollution control agencies, to the wastewater industry, and to consultants and designers of land-application systems.

Admittedly, there is insufficient knowledge about certain aspects of the treatment of sewage effluents by conventional secondary treatment as well as by land treatment to evaluate adequately all of the ramifications of the potential health hazards by any method of treating wastewater. EPA is proceeding with all deliberate speed, with its own resources and jointly with other institutions and agencies, to research these areas of insufficient knowledge. However, the successful and extensive use of the land treatment technique over a long period of time throughout the world justifies serious consideration of this method of treatment, even though, for example, it is not possible at this time to specify acceptable levels of contaminants in the soil from land application of wastewater. It must be demonstrated, however, that land treatment is the most cost-effective alternative, is consistent with the environmental assessment, and in other respects satisfies applicable tests.

As new aspects of land-application technology are developed through experience, additional information will become available, and this publication will be revised. All users are encouraged to submit suggested revisions and pertinent information to the Director, Municipal Construction Division, Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C. 20460.

James L. Agee

James L. Agee
Assistant Administrator for
Water and Hazardous Materials

## STATUTORY AND SUB-STATUTORY BASIS

The Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), the legislative history of the Act, and the regulations which have been issued in accordance with the provisions of the Act, provide the statutory basis for consideration and funding of land-application systems in the treatment of municipal wastewater.

### LEGISLATION

The rationale and goals within which land-application systems are to be considered are contained in the following sections of the Act:

Section 208 - Areawide Waste Treatment Management
Section 201 - Facilities Planning
Section 304 - Best Practicable Treatment Technology (BPT)
Section 212 - Cost Effectiveness Analysis

Concerning land application of municipal wastewater, the portions of these sections that are most important are reproduced here:

### Section 208

> "SEC. 208. (a) For the purpose of encouraging and facilitating the development and implementation of areawide waste treatment management plans—
>
> "(1) The Administrator, ........................................................ after consultation with appropriate Federal, State, and local authorities, shall by regulation publish guidelines for the identification of those areas which, as a result of urban-industrial concentrations or other factors, have substantial water quality control problems.

> "(b)(1) Not later than one year after the date of designation of any organization under subsection (a) of this section such organization shall have in operation a continuing areawide waste treatment management planning process consistent with section 201 of this Act. Plans prepared in accordance with this process shall contain alternatives for waste treatment management, and be applicable to all wastes generated within the area involved. The initial plan prepared in accordance with such process shall be certified by the Governor and submitted to the Administrator not later than two years after the planning process is in operation.
>
> "(2) Any plan prepared under such process shall include, but not be limited to—
>
> "(A) the identification of treatment works necessary to meet the anticipated municipal and industrial waste treatment needs of the area over a twenty-year period, annually updated (including an analysis of alternative waste treatment systems), including any requirements for the acquisition of land for treatment purposes; the necessary waste water collection and urban storm water runoff systems; and a program to provide the necessary financial arrangements for the development of such treatment works;

"(B) the establishment of construction priorities for such treatment works and time schedules for the initiation and completion of all treatment works;

"(C) the establishment of a regulatory program to—

"(i) implement the waste treatment management requirements of section 201(c),

"(ii) regulate the location, modification, and construction of any facilities within such area which may result in any discharge in such area, and

"(iii) assure that any industrial or commercial wastes discharged into any treatment works in such area meet applicable pretreatment requirements;

"(D) the identification of those agencies necessary to construct, operate, and maintain all facilities required by the plan and otherwise to carry out the plan;

"(E) the identification of the measures necessary to carry out the plan (including financing), the period of time necessary to carry out the plan, the costs of carrying out the plan within such time, and the economic, social, and environmental impact of carrying out the plan within such time;

"(F) a process to (i) identify, if appropriate, agriculturally and silviculturally related nonpoint sources of pollution, including runoff from manure disposal areas, and from land used for livestock and crop production, and (ii) set forth procedures and methods (including land use requirements) to control to the extent feasible such sources;

"(K) a process to control the disposal of pollutants on land or in subsurface excavations within such area to protect ground and surface water quality.

## Section 201

"Sec. 201. (a) It is the purpose of this title to require and to assist the development and implementation of waste treatment management plans and practices which will achieve the goals of this Act.

"(b) Waste treatment management plans and practices shall provide for the application of the best practicable waste treatment technology before any discharge into receiving waters, including reclaiming and recycling of water, and confined disposal of pollutants so they will not migrate to cause water or other environmental pollution and shall provide for consideration of advanced waste treatment techniques.

"(c) To the extent practicable, waste treatment management shall be on an areawide basis and provide control or treatment of all point and nonpoint sources of pollution, including in place or accumulated pollution sources.

"(d) The Administrator shall encourage waste treatment management which results in the construction of revenue producing facilities providing for—

"(1) the recycling of potential sewage pollutants through the production of agriculture, silviculture, or aquaculture products, or any combination thereof;

"(2) the confined and contained disposal of pollutants not recycled;

"(3) the reclamation of wastewater; and

"(4) the ultimate disposal of sludge in a manner that will not result in environmental hazards.

"(e) The Administrator shall encourage waste treatment management which results in integrating facilities for sewage treatment and recycling with facilities to treat, dispose of, or utilize other industrial and municipal wastes, including but not limited to solid waste and waste heat and thermal discharges. Such integrated facilities shall be designed and operated to produce revenues in excess of capital and operation and maintenance costs and such revenues shall be used by the designated regional management agency to aid in financing other environmental improvement programs.

"(f) The Administrator shall encourage waste treatment management which combines 'open space' and recreational considerations with such management.

"(g)(1) The Administrator is authorized to make grants to any State, municipality, or intermunicipal or interstate agency for the construction of publicly owned treatment works.

"(2) The Administrator shall not make grants from funds authorized for any fiscal year beginning after June 30, 1974, to any State, municipality, or intermunicipal or interstate agency for the erection, building, acquisition, alteration, remodeling, improvement, or extension of treatment works unless the grant applicant has satisfactorily demonstrated to the Administrator that—

> "(A) alternative waste management techniques have been studied and evaluated and the works proposed for grant assistance will provide for the application of the best practicable waste treatment technology over the life of the works consistent with the purposes of this title; and
>
> "(B) as appropriate, the works proposed for grant assistance will take into account and allow to the extent practicable the application of technology at a later date which will provide for the reclaiming or recycling of water or otherwise eliminate the discharge of pollutants.

### Section 304

"(d)(2) The Administrator, after consultation with appropriate Federal and State agencies and other interested persons, shall publish within nine months after the date of enactment of this title (and from time to time thereafter) information on alternative waste treatment management techniques and systems available to implement section 201 of this Act.

### Section 212

"Sec. 212. As used in this title—

"(1) The term 'construction' means any one or more of the following: preliminary planning to determine the feasibility of treatment works, engineering, architectural, legal, fiscal, or economic investigations or studies, surveys, designs, plans, working drawings, specifications, procedures, or other necessary actions, erection, building, acquisition, alteration, remodeling, improvement, or extension of treatment works, or the inspection or supervision of any of the foregoing items.

"(2)(A) The term 'treatment works' means any devices and systems used in the storage, treatment, recycling, and reclamation of municipal sewage or industrial wastes of a liquid nature to implement section 201 of this Act, or necessary to recycle or reuse water at the most economical cost over the estimated life of the works, including intercepting sewers, outfall sewers, sewage collection systems, pumping, power, and other equipment, and their appurtenances; extensions, improvements, remodeling, additions, and alterations thereof; elements essential to provide a reliable recycled supply such as standby treatment units and clear well facilities; and any works, including site acquisition of the land that will be an integral part of the treatment process or is used for ultimate disposal of residues resulting from such treatment.

"(B) In addition to the definition contained in subparagraph (A) of this paragraph, 'treatment works' means any other method or system for preventing, abating, reducing, storing, treating, separating, or disposing of municipal waste, including storm water runoff, or industrial waste, including waste in combined storm water and sanitary sewer systems. Any application for construction grants which

> includes wholly or in part such methods or systems shall, in accordance with guidelines published by the Administrator pursuant to subparagraph (C) of this paragraph, contain adequate data and analysis demonstrating such proposal to be, over the life of such works, the most cost efficient alternative to comply with sections 301 or 302 of this Act, or the requirements of section 201 of this Act.

## REGULATIONS

In addition to the legislation itself, regulations have been issued that pertain to land application. The following regulations represent a portion of the EPA program to implement requirements of Title II of the Act.

### Areawide Waste Treatment Management (Section 208)

The regulatory basis for Section 208 areawide waste treatment management planning pertaining to land-application systems is contained in 40 CFR 35, subpart F, published in the Federal Register May 13, 1974. The planning for areawide waste treatment management consists of two interrelated considerations: analysis and implementation. Analysis serves to identify important factors. Implementation involves practical aspects for realizing alternatives that can improve water quality. Under the Section 208 Interim Grant Regulation, implementation alternatives must consider all policy variables that can be adjusted to produce improvement of water quality. As one policy variable, land-application systems can play a significant role in development of areawide planning management alternatives.

Disposition of residual wastes and control of disposal of pollutants must be considered in formulation of areawide waste treatment management plans. Again, the consideration of land-application systems is a means for achieving this.

### Grants for Construction of Treatment Works (Section 201)

The Title II regulations set forth, in general, the procedures and conditions for award of grant assistance. Section 917 of these regulations specifies the facilities planning requirements, and Appendix A of these regulations gives the cost-effectiveness analysis guidelines. Both guidelines include mention of land application as alternative waste management systems.

Guidance for Facilities Planning - The publication, Guidance for Facilities Planning, March 1974, provides supplemental guidance and information regarding planning and evaluation of various alternatives for publicly-owned waste treatment works. Basically, facilities planning includes (1) a statement of the problems; (2) an inventory of existing systems; (3) a projection of future conditions; (4) setting of goals and objectives; (5) an evaluation of alternatives, which may variously include land treatment or reuse of wastewater, flow reduction measures (including the correction of excessive infiltration/flows, alternative system configurations, phased development of facilities, or improvements in operation and maintenance) to meet those goals and objectives; and (6) an assessment of the environmental impacts of the alternatives. Such planning provides for cost-effective and environmentally sound treatment works which will meet applicable effluent limitations.

Cost-Effectiveness Analysis Guidelines - Regulations for the cost-effectiveness analysis (40 CFR 35 Appendix A), published in the Federal Register on September 10, 1973, provide information for determining the most cost-effective waste treatment management system or the most cost-effective component part of any waste treatment management system, including the identification, selection, and screening of alternative waste management systems. These alternatives should include systems discharging to receiving waters, systems using land or subsurface disposal techniques, and systems employing the reuse of wastewater. A complete text of the guidelines is included herein as Appendix G.

Secondary Treatment Information (Section 304 (d)(1))

Information on secondary treatment (40CFR 133) was published in the Federal Register on August 17, 1973. Land-application systems with point source discharges must comply with these minimum standards.

Alternative Waste Management Techniques for Best Practicable Waste Treatment (Section 304 (d)(2))

This publication provides information on best practicable treatment technology (BPT) and contains information and criteria for waste management techniques involving land application. The proposed BPT criteria for a land-application system where the effluent results in permanent groundwater are based on protection of groundwater for drinking water supply purposes. The proposed version, dated March 1974, is now being finalized.

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# INTRODUCTION

The purpose of this publication is to suggest procedures for the evaluation and review of municipal wastewater treatment system alternatives that employ the land application of effluent. It is not intended to be used as a design guide. An Evaluation Checklist and background information are provided, and procedures are given for evaluating alternatives dealing with irrigation, infiltration-percolation, overland flow, or combinations of these land-application approaches. Systems involving injection wells, sealed evaporation ponds, or septic-tank leach fields for wastewater disposal are excluded, as are systems in which sludge is applied to the land.

To properly evaluate each step involved in planning, design, and operation of soil systems, the Evaluation Checklist is divided into three major parts dealing with: (1) facilities plans, (2) design plans and specifications, and (3) operation and maintenance manuals. Organization of the text containing the background information parallels the Evaluation Checklist and is keyed to it by appropriate symbols in the headings.

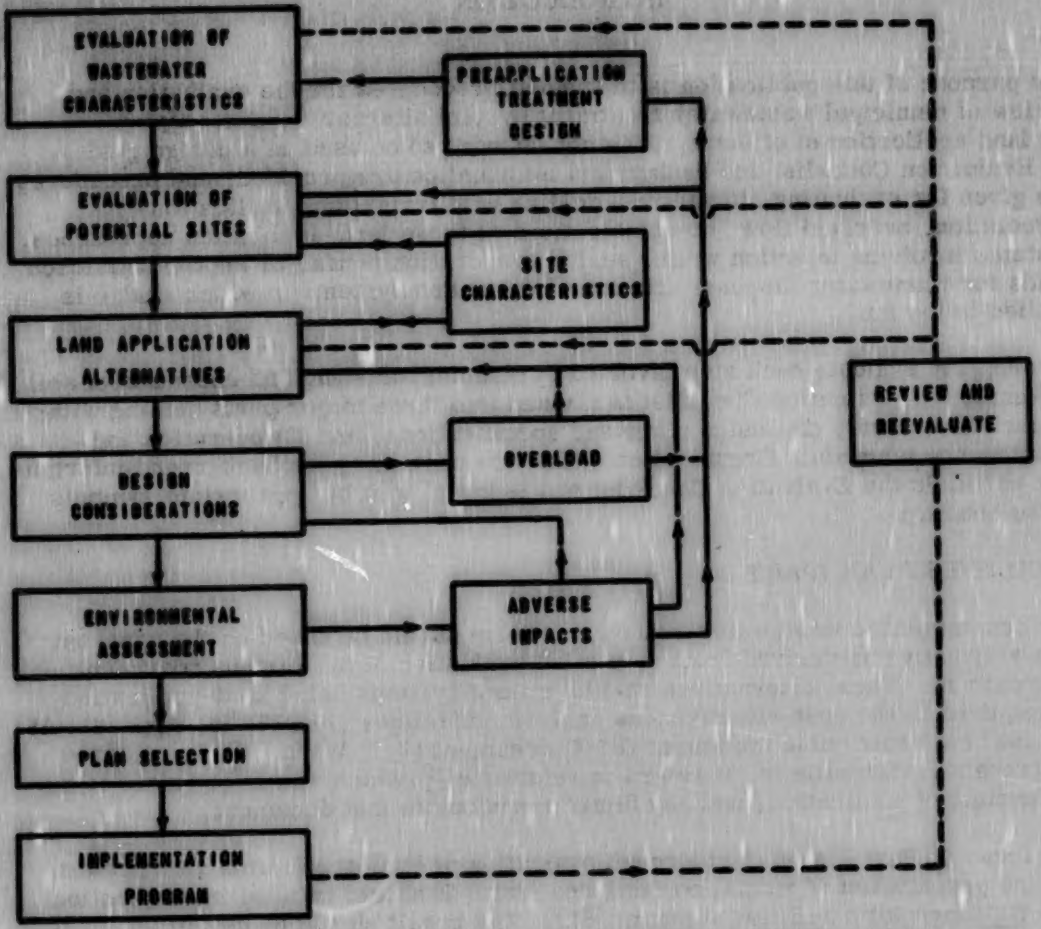
## FACILITIES PLAN (PART I)

The recommended wastewater management plan should be based on the apparent best alternative as derived from a detailed evaluation of the various treatment alternatives. These alternatives should include systems using land-application as required in the cost-effectiveness analysis guidelines (40 CFR 35, Appendix A) and the best practicable treatment (BPT) document [3]. When BPT is referred to throughout this bulletin, it refers to reference [3], which was in proposed form at the time of publication, and any future revisions to that document.

The focus of Part I is on the thorough evaluation of land-application alternatives, and the preparation of a detailed facilities plan. It should be used in conjunction with Guidance for Facilities Planning [62]. The result should be definitive regarding design criteria, so that design plans and specifications may easily follow. An attempt has been made to avoid restrictive or dogmatic standards because most design criteria are site-specific. Instead, important considerations are discussed and reasonable ranges suggested. Key elements to consider are: (1) Did the engineer consider appropriate land-application approaches or combinations and modifications thereof, and (2) What was the basis for screening the land-application alternatives?

Emphasis is placed on long-range planning and environmental factors. Are the alternatives compatible with local and regional planning goals and objectives? With regard to environmental factors, a careful assessment must be made of the completeness and detail of the investigation and the overall design considerations provided to minimize any adverse impacts.

The normal sequence and interrelationship of steps in the preparation of a wastewater management plan are presented in Figure 1. For the most part,


EVALUATION OF WASTEWATER CHARACTERISTICS
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REVIEW AND REEVALUATE
OVERLOAD
DESIGN CONSIDERATIONS
ENVIRONMENTAL ASSESSMENT
ADVERSE IMPACTS
PLAN SELECTION
IMPLEMENTATION PROGRAM

Figure 1. Planning sequence for land-application alternatives

these steps correspond directly in title and sequence to the sections in Part I. The planning process involves repeating the sequence of steps until the implementation program is finalized.

DESIGN PLANS AND SPECIFICATIONS (PART II)

The design plans and specifications should be a logical extension of the facilities plan. Details of the wastewater management plan are presented in the plans and specifications for implementation and construction purposes. A complete listing of site characteristics and major design criteria should accompany or be included in the plans and specifications for ease in evaluation. Important considerations in design are discussed in Part II with stress placed on the continuity between recommendations in the facilities plan and features of the design.

## OPERATION AND MAINTENANCE MANUAL (PART III)

The Operation and Maintenance Manual is a tool of fundamental importance for management of the treatment system. The design concepts should be clearly explained and procedures for operating and maintaining the facilities must be delineated. The manual is intended to be a guide for the operators of the treatment facilities and will help to ensure that they understand the key design features and the objectives for which the system was designed. The manual should include maintenance schedules, monitoring programs, and recommendations for manpower utilization. Additionally, potential problem areas, symptoms of process malfunction, and methods of control of adverse impacts should be described. Special considerations, such as agricultural practices for irrigation systems, should also be included.

Extensive reference is made to Considerations for the Preparation of Operation and Maintenance Manuals [61] throughout Part III, and Section A is devoted entirely to a discussion of the use of this reference. In the remaining three sections, additional considerations particular to operation and maintenance manuals for land-application systems are presented.

## CONSIDERATION OF SYSTEM SIZE

The scope of the Evaluation Checklist is aimed at moderate-to-large sized land-application systems. The extent to which planning and design of small systems (say 0.5 mgd or less) should adhere to all points in the checklist is left to the discretion of the evaluator.

## SOURCES OF DATA

Throughout this report, major sources of information on each subject are cited for easy references. These sources should not be viewed as the only ones available; when appropriate, other interested agencies, such as the USDA and FDA, or local government, university, or independent consultants should be sought out for pertinent data. References cited by bracketed numbers in the text are listed in alphabetical order in Appendix A. A short annotated bibliography of the major reports on land application of wastewater is included as Appendix B.

## PUBLIC ACCEPTANCE

In many cases, public acceptance may be the primary limiting factor in the implementation of land-application projects. At each step in the review process, the evaluator should ensure that areas of public concern have been identified, and that these concerns are reflected in the facilities plan, plans and specifications, and operation and maintenance manual.

One source of public concern is often the relative uncertainty over various health effects. With regard to this concern, the evaluator should pay particular attention to such items as the degree of preapplication treatment, types of crops that may be grown, and the degree of public contact with the effluent.

# EVALUATION CHECKLIST FOR TREATMENT ALTERNATIVES EMPLOYING LAND APPLICATION OF WASTEWATER

The purpose of this checklist is to provide reviewers with the pertinent factors to be considered in the planning, design, and operation of systems employing land application of municipal effluents. The format of the checklist has been selected to enable the reviewer to enter a check mark or comment to the right of each item. Items are arranged so that the more important ones appear first. Those items for which a dashed checkline appears are desirable but not essential considerations. The notation and headings used are generally the same as those used in the background information text.

## Part I FACILITIES PLAN

### A. Project Objectives

Objectives and goals relevant to water quality, protection of groundwater aquifer, the need for augmenting existing water resources, and any other desired effects should be considered initially.

### B. Evaluation of Wastewater Characteristics

1. Flowrates
   Present, projected, and peak flow ________
2. Existing treatment
   a. Description ________
   b. Adequacy for intended project ________
3. Existing effluent disposal facilities
   a. Description ________
   b. Consideration of water rights ________
4. Composition of effluent to be applied
   a. Total dissolved solids ________
   b. Suspended solids ________
   c. Organic matter (BOD, COD, TOC) ________
   d. Nitrogen forms (all) ________
   e. Phosphorus ________

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I-B.4. (continued)

f. Inorganic ions

(1) Heavy metals and trace elements

(2) Exchangeable cations (SAR)

(3) Boron

g. Bacteriological quality

h. Projected changes in characteristics

i. Are industrial wastewater components considered?

j. BPT constituents

## C. Evaluation of Potential Sites

All potential sites should be considered on the basis of the criteria listed in this section, and should be reevaluated in the light of design considerations and environmental assessment.

1. General description

a. Location

(1) Distance from collection area or treatment plant

(2) Elevation relative to collection area

b. Compatibility with overall land-use plan

(1) Current use

(2) Proposed future use

(3) Zoning and adjacent land use

(4) Proximity to current and planned developed areas

(5) Is there room for future expansion?

c. Proximity to surface water

d. Number and size of available land parcels

2. Description of environmental characteristics

a. Climate

(1) Precipitation analysis and seasonal distribution

(2) Storm intensities

I-C.2.a. (continued)

- (3) Temperature, with seasonal variations ________
- (4) Evapotranspiration ________
- (5) Wind velocities and direction ________

b. Topography

- (1) Ground slope ________
- (2) Description of adjacent land ________
- (3) Erosion potential ________
- (4) Flood potential ________
- (5) Extent of clearing and field preparation necessary ________

c. Soil characteristics

- (1) Type and description ________
- (2) Infiltration and percolation potential ________
- (3) Soil profile ________
- (4) Evaluation by soil specialists ________

d. Geologic formations

- (1) Type and description ________
- (2) Evaluation by geologist ________
- (3) Depth of formations ________
- (4) Earthquake potential ________

e. Groundwater

- (1) Depth to groundwater ________
- (2) Groundwater flow ________
- (3) Depth and extent of any perched water ________
- (4) Quality compared to requirements ________
- (5) Current and planned use ________
- (6) Location of existing wells
  - (a) On site ________
  - (b) Adjacent to site ________

f. Receiving water (other than groundwater)

- (1) Type of body ________

I-C.2.f. (continued)

- (2) Current use ________
- (3) Existing quality ________
- (4) Is it water-quality limited? ________
- (5) Is it effluent limited? ________
- (6) Water rights ________

3. Methods of land acquisition or control
    - a. Purchase ________
    - b. Lease ________
    - c. Purchase and lease back to farmer ________
    - d. Contract with users ________
    - e. Other ________

D. Consideration of Land-Application Alternatives

Based on the project objectives and characteristics of the selected potential sites, appropriate methods of land application should be considered.

1. Irrigation
    - a. Purpose
        - (1) Optimization of crop yields ________
        - (2) Maximization of effluent application ________
        - (3) Landscape irrigation ________
    - b. Application techniques
        - (1) Spraying ________
        - (2) Ridge and furrow ________
        - (3) Flooding ________
2. Infiltration-percolation
    - a. Purpose
        - (1) Groundwater recharge ________
        - (2) Pumped withdrawal or underdrains ________
        - (3) Interception by surface water ________
    - b. Application techniques
        - (1) Spreading ________
        - (2) Spraying ________

I-D. (continued)

- 3. Overland flow (spray-runoff)
  - a. Purpose
    - (1) Discharge to surface waters ________
    - (2) Reuse of collected runoff ________
  - b. Application techniques
    - (1) Spraying ________
    - (2) Flooding ________
- 4. Combinations of treatment techniques
  - a. Combinations of land-application techniques at the same or different sites — — —
  - b. Combinations of land-application with in-plant treatment and receiving water discharge — — —
- 5. Compatibility with site characteristics ________

E. Design Considerations

- 1. Loading rates
  - a. Liquid loading/water balance
    - (1) Design precipitation ________
    - (2) Effluent application ________
    - (3) Evapotranspiration ________
    - (4) Percolation ________
    - (5) Runoff (for overland flow systems) ________
  - b. Nitrogen mass balance
    - (1) Total annual load ________
    - (2) Total annual crop uptake ________
    - (3) Denitrification and volatilization ________
    - (4) Addition to groundwater or surface water ________
  - c. Phosphorus mass balance ________
  - d. Organic loading rate (BOD)
    - (1) Daily loading ________
    - (2) Resting-drying period for oxidation ________
  - e. Loadings of other constituents ________

I-E. (continued)

2. Land requirements
    a. Field area requirement ______
    b. Buffer zone allowance ______
    c. Land for storage ______
    d. Land for buildings, roads and ditches ______
    e. Land for future expansion or emergencies ______
3. Crop selection
    a. Relationship to critical loading parameter ______
    b. Public health regulations ______
    c. Ease of cultivation and harvesting ______
    d. Length of growing season ______
    e. Landscape requirements — — —
    f. Forestland — — —
4. Storage requirements
    a. Related to length of operating season and climate ______
    b. For system backup ______
    c. For flow equalization ______
    d. Secondary uses of stored wastewater ______
5. Preapplication treatment requirements
    a. Public health considerations ______
    b. Relationship to loading rate ______
    c. Relationship to effectiveness of physical equipment ______
6. Management considerations
    a. System control and maintenance ______
    b. Manpower requirements ______
    c. Monitoring requirements ______ -
    d. Emergency procedures ______
7. Cost-effectiveness analysis
    a. Capital cost considerations ______
        (1) Construction or other cost index ______
        (2) Service life of equipment ______
        (3) Land cost ______

I-E.7. (continued)

b. Fixed annual costs
   (1) Labor ________
   (2) Maintenance ________
   (3) Monitoring ________
c. Flow-related annual costs
   (1) Power ________
   (2) Crop sale or disposal ________
d. Nonmonetary factors ________

8. Flexibility of alternative
   a. With regard to changes in treatment requirements ________
   b. With regard to changes in wastewater characteristics ________
   c. For ease of expansion ________
   d. With regard to changing land utilization _ _ _
   e. With regard to technological advances _ _ _

9. Reliability
   a. To meet or exceed discharge requirements ________
   b. Failure rate due to operational breakdown ________
   c. Vulnerability to natural disasters ________
   d. Adequate supply of required resources ________
   e. Factors-of-safety ________

10. Best practicable waste treatment technology (BPT)
   a. Requirements for groundwater quality ________
   b. Requirements for treatment and discharge ________

F. Environmental Assessment

The impact of the project on the environment, including public health, social, and economic aspects must be assessed for each land-application alternative.

1. Environmental impact
   a. On soil and vegetation ________
   b. On groundwater
      (1) Quality ________

I-F.1.b. (continued)

(2) Levels and flow direction
c. On surface water
(1) Quality
(2) Influence on flow
d. On animal and insect life
e. On air quality
f. On local climate
2. Public health effects
a. Groundwater quality
b. Insects and rodents
c. Runoff from site
d. Aerosols
e. Contamination of crops
3. Social impact
a. Relocation of residents
b. Effects on greenbelts and open space
c. Effect on recreational activities
d. Effect on community growth
4. Economic impact
a. On overall local economy
b. Tax considerations (land)
c. Conservation of resources and energy

G. Implementation Program

The ability to implement the project must be assessed in light of the overall impact, the effectiveness of the tentative design, and with regard to public opinion.

1. Public information program
a. Approaches to public presentation
(1) Local officials
(2) Public hearings
(3) Mass media

I-G.1.a. (continued)

(4) Local residents and land owners ________

(5) Communication with special-interest groups ________

b. Public opinion

(1) Engineer's response ________

(2) Review of problem areas ________

2. Legal considerations ________

3. Reevaluation of ability to implement project ________

4. Implementation schedule

a. Construction schedule ________

b. Long-range management plan ________

# EVALUATION CHECKLIST FOR TREATMENT SYSTEMS EMPLOYING LAND APPLICATION OF WASTEWATER

## Part II DESIGN PLANS AND SPECIFICATIONS

The purpose of this part is to ensure completeness of the engineering design considerations and to assess the compatibility of the design with the facilities plan.

A. Agreement with Facilities Plan
  1. Modifications
    a. Have modifications affected other design criteria? ______
    b. Is supporting material included? ______
    c. Were pilot studies recommended in the report? — — —
  2. Reevaluation of facilities plan
    a. With regard to changes in the interim period
      (1) In federal or state regulations ______
      (2) In basin planning ______
    b. With regard to findings of pilot studies — — —

B. Site Characteristics
  1. Topography
    a. Site plan ______
    b. Effects of adjacent topography
      (1) Will it add storm runoff? ______
      (2) Will it back up water onto site? ______
      (3) Will it provide relief for drainage? ______
    c. Erosion-prevention considerations ______
    d. Earthwork required
      (1) For field preparation ______
      (2) For transmission, storage, and roads ______

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II-B.1. (continued)

e. Method of disposal of trees, brush, and debris ________

2. Soil

a. Soil maps ________

b. Soil profiles

(1) Location ________

(2) Physical and chemical analysis ________

3. Geohydrology

a. Map of important geologic formations ________

b. Analysis of geologic discontinuities ________

c. Groundwater analysis ________

C. Design Criteria

1. Climatic factors

a. Precipitation

(1) Total annual precipitation ________

(2) Record maximum and minimum annual ________

(3) Monthly distribution ________

(4) Storm intensities ________

(5) Effects of snow ________

b. Temperature

(1) Monthly or seasonal averages and variation ________

(2) Length of growing season ________

(3) Period of freezing conditions ________

c. Wind ________

2. Infiltration and percolation rates

a. Design rates ________

b. Basis of determination

(1) Agriculture extension service or soil specialists ________

(2) From soil borings and profiles ________

(3) From analysis of SCS soil surveys ________

II-C.2.b. (continued)

        (4) From farming experience ________
        (5) From results of pilot studies — — —

    3. Loading rates
        a. List of loading rates ________
        b. Critical loading rate ________
    4. Land requirements
        a. Application area
            (1) Wetted area ________
            (2) Field area ________
        b. For buffer zones ________
        c. For storage ________
        d. For preapplication treatment, buildings, and roads ________
        e. For future or emergency needs ________
    5. Application rates and cycle
        a. Annual liquid loading rate ________
        b. Length of operating season ________
        c. Application cycle
            (1) Application period and rate ________
            (2) Weekly application rate ________
            (3) Resting or drying period ________
            (4) Rotation of plots or basins ________
    6. Crops/vegetation
        a. Compatibility with site characteristics and loading rates ________
        b. Nutrient uptake ________
        c. Cultivation and harvesting requirements ________
        d. Suitability for meeting health criteria ________
    7. System components
        a. Preapplication treatment facilities ________
        b. Transmission facilities ________
        c. Storage facilities ________
        d. Distribution system ________

II-C.7. (continued)
e. Recovery system ________
f. Monitoring system ________
8. Design flexibility
a. Provisions for system expansion ________
b. Provisions for system modification ________
c. Interconnections and partial isolation ________
9. Reliability
a. Factors-of-safety ________
b. Backup systems ________
c. Contingency provisions
(1) Equipment or unit failure ________
(2) Natural disasters ________
(3) Severe weather ________
(4) Unexpected peak flows ________
D. Expected Treatment Performance
1. Removal efficiencies for major constituents ________
2. Remaining concentrations in renovated water ________

## EVALUATION CHECKLIST FOR TREATMENT SYSTEMS EMPLOYING LAND APPLICATION OF WASTEWATER

### Part III OPERATION AND MAINTENANCE MANUAL

The operation and maintenance manual should be prepared in accordance with EPA guidelines that deal specifically with the subject; however, special considerations for land-application systems are presented.

A. EPA – Considerations for Preparation of Operation and Maintenance Manuals

   1. Introduction ________
   2. Permits and standards ________
   3. Description, operation, and control of wastewater treatment facilities ________
   4. Description, operation, and control of sludge-handling facilities ________
   5. Personnel ________
   6. Laboratory testing ________
   7. Records ________
   8. Maintenance ________
   9. Emergency operating and response program ________
   10. Safety ________
   11. Utilities ________
   12. Electrical system ________
   13. Appendixes ________

B. Operating Procedures

   1. Application of effluent
      a. Distribution system ________
      b. Schedule of application ________
   2. Agricultural practices
      a. Purpose of crop ________
      b. Description of crop requirements ________
      c. Planting, cultivation, and harvesting ________

III-B. (continued)

- 3. Recovery of renovated water ______
- 4. Storage ______
- 5. Special problems and emergency conditions ______

C. Monitoring

- 1. Parameters to be monitored ______
- 2. Monitoring procedures ______
  - a. Location of sampling points ______
  - b. Schedule of sampling ______
- 3. Interpretation of results ______
- 4. Surveillance and reporting ______

D. Impact Control

- 1. Description of possible adverse effects
  - a. Environmental ______
  - b. Public health ______
  - c. Social ______
  - d. Economic ______
- 2. Indexes of critical effects ______
- 3. Methods of control ______
- 4. Methods of remedial action ______

# PART I

# WASTEWATER MANAGEMENT PLAN

## Section A

## PROJECT OBJECTIVES

Proper evaluation of land application of wastewater as a treatment alternative requires that a clear set of project goals and objectives be established. The success of the project will depend to a large degree upon the careful formulation of these objectives. Some of the major questions that should be answered are:

- What are the immediate and long-term water-quality objectives?
- Is there potential for meeting the BPT requirements for protecting groundwater?
- Is there a need to consider wastewater as a means of augmenting existing water resources?
- What are the areal plans and policies for land use?
- Is there a need to minimize land requirements?
- Is there a need to minimize use of resources (or energy)?

Immediate and long-term water-quality objectives should be determined for both surface waters and groundwater in order that treatment requirements may be assessed for potential systems. These objectives should be related to both the basin water quality management plan (40 CFR 131), and the areawide waste treatment plan (40 CFR 35.1050). Critical parameters and constituents, and special water-quality problems of a particular area should be identified.

The BPT requirements [3] establish a need to protect all groundwater to some level. As stated in the BPT document, "land application practices should not further degrade the air, land, or navigable waters; should not interfere with the attainment or maintenance of public health, state, or local land use policies; and should insure the protection of public water supplies, agricultural and industrial water uses, propagation of a balanced population of aquatic and land flora and fuana, and recreational activities in the area." The water-quality criteria for drinking water supplies are the most thoroughly defined of the above objectives, and may often be adequate alone. However, there may be instances where more stringent quality criteria may be required to protect beneficial uses other than drinking water. A determination should be made of the potential for meeting the BPT requirements for protecting groundwater based on the effluent quality to be applied (I-B.4), the site and groundwater characteristics (I-C.2), the type of land-application system (I-D), and design loading rates (I-E.1).

The overall water-use plan should be evaluated to determine the value of using wastewater to augment existing water resources. For many areas, the reuse of wastewater may offer new water-use possibilities, or may relieve requirements for fresh water. Irrigation, groundwater recharge, and water-based recreation are water-use possibilities that could be investigated.

Land-use trends and plans should be evaluated to determine if a land-application system would be compatible with other land uses, and if land exists that may benefit from land application of effluent. The need for land for other purposes, such as industrial, commercial, or residential expansion should be determined, as should beneficial effects, such as development of agricultural land, parks, or greenbelts.

The availability of land may be limited or land costs may be high in many densely populated or developed areas. The need to minimize land requirements will then become an important consideration in which high-rate application systems, such as infiltration-percolation and overland flow, are emphasized.

Resources necessary for various treatment alternatives that must be conserved should be noted. Materials and chemicals required for certain treatment processes, and energy are among those resources that may be limited in supply and must be conserved.

## Section B

## EVALUATION OF WASTEWATER CHARACTERISTICS

A necessary preliminary step when planning for a land-application system, as with any other treatment system, is a detailed evaluation of the wastewater characteristics. The characteristics will, to some degree, affect the treatment method – whether irrigation, overland flow, or infiltration-percolation – and will directly affect the system design. Evaluation of the wastewater characteristics should include: (1) flowrates, (2) quality changes resulting from existing treatment, (3) existing effluent disposal practices, and (4) composition of effluent.

### B.1. FLOWRATES

The quantity of effluent to be treated by the land-application system should be estimated as closely as possible. Clearly, the success of the project will depend to a large degree on the accuracy of estimating flowrates. Flowrates which should be estimated include:

- Present or initial flow
- Present sustained peak flow
- Projected future flow
- Projected sustained peak flow

Instantaneous peaks (less than 1 hour in duration) will have little effect on most designs; however, sustained peaks for 3 or 4 hours or more may require special design features in pumping, preapplication treatment, or storage. In some cases, industrial flows, such as from canneries, may result in seasonal peaks lasting for several months. In such cases, special provisions must be made, such as using additional land.

Stormwater must be considered for combined sewer systems and an infiltration/inflow analysis must be conducted on sanitary sewer systems to determine the extent of groundwater or stormwater infiltration. The EPA publication on urban stormwater management and technology [79] will be a useful reference for assessing the magnitude of stormwater flows and the problems that may be encountered. Infiltration/inflow analysis should be conducted in accordance with Federal Regulation 35.927 [59] and the EPA publication entitled, Guidance for Sewer System Evaluation [63]. Where large sustained peaking factors exist as a result of infiltration/inflow or industrial/commercial activity, consideration may be given to storage for flow equalization.

## B.2. EXISTING TREATMENT

Where land application is to be used, varying degrees of preapplication treatment, ranging from primary screening to secondary treatment with advanced treatment for certain constituents may be required. The degree of preapplication treatment necessary will depend upon a number of factors, including the land-application method, the effluent limitations established, the groundwater-quality criteria established in the BPT document [3], and the design features of the system (see I-E.5). In most cases where land application is to be an additional step, existing treatment facilities may partially fulfill preapplication treatment requirements. The existing facilities should be evaluated for capacity, degree of treatment, and adaptability for land-application alternatives.

## B.3. EXISTING EFFLUENT DISPOSAL FACILITIES

Existing effluent disposal practices should be described as they relate to the overall basin hydrology. Existing and proposed effluent or water-quality standards should be specified, and the record of effluent quality should be reviewed. The two should be compared and any discrepancies should be explained. Existing water rights should be investigated if a change is anticipated in disposal practice. In the western states, where water rights are generally of greater concern, it may be helpful to consult with the state agency involved in water rights.

## B.4. COMPOSITION OF EFFLUENT

The composition of the effluent to be applied to the land should be evaluated with respect to the constituents in the following discussion. The constituents of importance in an individual case will depend upon the effluent limitations, groundwater protection criteria from the BPT document, and guidelines for irrigation water quality. The concentrations determined should be related to existing preapplication treatment practices and to additional preapplication treatment requirements as discussed in Section E. The degree to which the list is adhered to is dependent upon the type and size of the project, and the sources of wastewater. Where high constituent concentrations are suspected, they should be evaluated more thoroughly. Because the acceptability of wastewater characteristics for land application will depend heavily upon site characteristics, type and purpose of system, and loading rates, the evaluation cannot be completed until these interactions are considered.

### B.4.a. Total Dissolved Solids

The aggregate of the dissolved compounds is the TDS (total dissolved solids). The TDS content, which is related to the EC (electrical conductivity), is generally more important than the concentration of any specific ion. High TDS (total dissolved solids) wastewater can cause a salinity hazard to crops, expecially where annual evapotranspiration exceeds annual precipitation. A general classification as to salinity hazard by TDS content and electrical conductivity is given in Table 1. It should be noted that these values were developed primarily for the arid and semiarid parts of the country. The effects of high TDS on crop yields are discussed in Section E (I-E.3.a.). High-TDS wastewater may also create problems if allowed to percolate to the permanent groundwater.

Table 1. GENERAL GUIDELINES FOR SALINITY IN IRRIGATION WATER[a] [110]

| Classification[b] | TDS, mg/l | EC, mmhos/cm |
|---|---|---|
| Water for which no detrimental effects are usually noticed | 500 | 0.75 |
| Water that can have detrimental effects on sensitive crops | 500-1,000 | 0.75-1.50 |
| Water that can have adverse effects on many crops, requiring careful management practices | 1,000-2,000 | 1.50-3.00 |
| Water that can be used for tolerant plants on permeable soils with careful management practices | 2,000-5,000 | 3.00-7.50 |

a. Normally only of concern in arid and semiarid parts of the country.

b. Crops vary greatly in their tolerance to salinity (TDS or EC). Crop tolerances are given in Section E.

### B.4.b. Suspended Solids

Suspended solids in applied effluents are important because they have a tendency to clog sprinkler nozzles and soil pores and to coat the land surface. A large percentage of the suspended solids can be removed easily by sedimentation. When applied to the land at acceptable loading rates, almost complete removal can be expected from the percolate.

### B.4.c. Organic Matter

Organic matter, as measured by BOD, COD, and TOC, is present in the dissolved form as well as in the form of suspended and colloidal solids. Ordinarily, concentrations are low enough not to cause any short-term effects on the soil or vegetation. Organic compounds, such as phenols, surfactants, and pesticides, are usually not a problem but in high concentrations they can be toxic to microorganisms.

BOD applied is removed from the wastewater very efficiently by each land-application method. The loading applied, however, will greatly influence the resting period for soil reaeration and may influence liquid loading rates (I.E.1.d.).

For groundwater quality protection, the organic forms to be considered include carbon chloroform extractable and carbon alcohol extractable compounds as well as pesticides and foaming agents. There are few data on removal of these compounds by soils from applied municipal effluents.

### B.4.d Nitrogen Forms

Nitrogen contained in wastewater may be present as: ammonium, organic, nitrate, and nitrite; with ammonium and organic usually being the principal forms. In a nitrified effluent, however, nitrate nitrogen will be the major form. Relationships between these forms and renovation mechanisms for land-application treatment systems are explained in references [125, 130, 141]. Because nitrogen removal is sensitive to a variety of environmental conditions, monitoring of nitrogen concentrations is usually required. To avoid confusion, concentrations of each form should be expressed as nitrogen.

Nitrogen is important because when it is converted to the nitrate form, it is mobile and can pass through the soil matrix with the percolate. In groundwater, nitrates are limited to 10 mg/l by the proposed BPT criteria, while in surface waters nitrates may also aggravate problems of eutrophication. Nitrogen loadings and removal mechanisms are discussed in Section E (I-E.1.b.).

### B.4.e. Phosphorus

Phosphorus contained in wastewater occurs mainly as inorganic compounds, primarily phosphates, and is normally expressed as total phosphorus. Phosphorus removal is accomplished through plant uptake and by fixation in the soil matrix. The long-term loadings of phosphorus are important because the fixation capability of some soils may be limited over the normal expected lifespan of the system (I-E. 1.c.). Phosphorus that reaches surface waters as a result of surface runoff or interception of groundwater flow may aggravate problems of eutrophication. Detailed discussions of phosphorus reactions in soil are contained in Bailey [9] and Reed [130].

### B.4.f. Inorganic Ions

Inorganic chemical constituents in wastewater can present problems to land-application systems, through the effect of specific ions on the soil, plants, and groundwater. Irrigation requirements for chlorides, sulfates, boron, and carbonates are detailed in Water Quality Criteria [110, 176]. Concentrations of TDS, boron, sodium, chlorides, and carbonates that could cause various deleterious effects on plants are listed in Table 2. In most cases, the concentrations present in municipal wastewater are within these limits; however, a complete mineral analysis of the wastewater should be conducted. Problems encountered from high boron concentrations and high sodium adsorption ratios

## Table 2. WATER-QUALITY GUIDELINES [7]

| Problem and related constituent | Guideline values<br>No problem | <br>Increasing problems | <br>Severe |
|---|---|---|---|
| **Salinity**[a] | | | |
| EC of irrigation water, in millimhos/cm | <0.75 | 0.75–3.0 | >3.0 |
| **Permeability** | | | |
| EC of irrigation water, in mmho/cm | >0.5 | <0.5 | <0.2 |
| SAR (Sodium adsorption ratio) | <6.0 | 6.0–9.0 | >9.0 |
| **Specific ion toxicity**[b] | | | |
| From root absorption | | | |
| Sodium (evaluate by SAR) | <3 | 3.0–9.0 | >9.0 |
| Chloride, me/l | <4 | 4.0–10 | >10 |
| Chloride, mg/l | <142 | 142–355 | >355 |
| Boron, mg/l | <0.5 | 0.5–2.0 | 2.0–10.0 |
| From foliar absorption[c] (sprinklers) | | | |
| Sodium, me/l | <3.0 | >3.0 | -- |
| Sodium, mg/l | <69 | >69 | -- |
| Chloride, me/l | <3.0 | >3.0 | -- |
| Chloride, mg/l | <106 | >106 | -- |
| **Miscellaneous**[d] | | | |
| $NH_4$-N, $NO_3$-N mg/l for sensitive crops | <5 | 5–30 | >30 |
| $HCO_3$, me/l [only with overhead sprinklers] | <1.5 | 1.5–8.5 | >8.5 |
| $HCO_3$, mg/l [only with overhead sprinklers] | <90 | 90–520 | >520 |
| pH | Normal range = | 6.5–8.4 | -- |

a. Assumes water for crop plus needed water for leaching requirement (LR) will be applied. Crops vary in tolerance to salinity. Refer to tables for crop tolerance and LR. mmho/cm x 640 = approximate total dissolved solids (TDS) in mg/l or ppm; mmho x 1,000 = micromhos.

b. Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive (use salinity tolerance tables).

c. Leaf areas wet by sprinklers (rotating heads) may show a leaf burn due to sodium or chloride absorption under low-humidity, high-evaporation conditions. (Evaporation increases ion concentration in water films on leaves between rotations of sprinkler heads.)

d. Excess N may affect production or quality of certain crops, e.g., sugar beets, citrus, grapes, avocados, apricots, etc. (1 mg/l $NO_3$-N = 2.72 lb N/acre-ft of applied water.) $HCO_3$ with overhead sprinkler irrigation may cause a white carbonate deposit to form on fruit and leaves.

Note: Interpretations are based on possible effects of constituents on crops and/or soils. Guidelines are flexible and should be modified when warranted by local experience or special conditions of crop, soil, and method of irrigation.

are perhaps the most common; however, heavy metals and trace elements can also cause problems. Recommended maximum concentrations for trace elements in irrigation waters are given in Table 3. For groundwater quality protection, the constituents included in the BPT criteria are of importance.

B.4.f.1. Heavy Metals and Trace Elements – Although some heavy metals are essential in varying degrees for plant growth, most are toxic, at varying levels, to both plant life and microorganisms. The major risk to land treatment systems from heavy metals is in the long-term accumulation in the soil, because they are retained in the soil matrix by adsorption, chemical precipitation, and ion exchange. Retention capabilities are generally good for most metals in most soils especially for pH values above 7. Page [113], Chapman [27], and Mortvedt [107] have reviewed and discussed the fate and effects of heavy metals in soils.

Generally, zinc, copper, and nickel make the largest contributions to the total heavy metal content. Zinc is used as a standard for plant toxicity, with copper being twice as toxic and nickel being eight times as toxic [63]. A "zinc equivalent" can thus be determined for these two metals. Research is continuing in an attempt to determine the relative phytotoxicities of other metals. For infiltration-percolation systems the effects of heavy metals reaching the groundwater must be considered (see I-C.2.e.).

B.4.f.2. Exchangeable Cations – The effect of concentrations of sodium, calcium, and magnesium ions deserves special consideration. They are related by the sodium adsorption ratio (SAR), defined as [37]:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca} + \mathrm{Mg}}{2}}} \qquad (1)$$

where Na, Ca, and Mg are the concentrations of the respective ions in milliequivalents per liter of water. High SAR (greater than 9) values may adversely affect the permeability of soils [7]. Other exchangeable cations, such as ammonium and potassium, may also react with soils. High sodium concentrations in soils can also be toxic to plants, although the effects on permeability will generally occur first [110].

B.4.f.3. Boron – Boron is an essential plant micronutrient but is toxic to many plants at 1 to 2 mg/l [96]. In addition to the limited plant uptake, boron can be removed from solution by adsorption and fixation in the soil in the presence of iron and aluminum oxides [20], but only to a limited extent [130]. Relative tolerances of various plants to boron are presented in references [27, 37, 176].

## Table 3. RECOMMENDED MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN IRRIGATION WATERS [110][a]

| Element | For waters used continuously on all soil, mg/l | For use up to 20 years on fine-textured soils of pH 6.0 to 8.5, mg/l |
|---|---|---|
| Aluminum | 5.0 | 20.0 |
| Arsenic | 0.10 | 2.0 |
| Beryllium | 0.10 | 0.50 |
| Boron | 0.75 | 2.0-10.0 |
| Cadmium | 0.010 | 0.050 |
| Chromium | 0.10 | 1.0 |
| Cobalt | 0.050 | 5.0 |
| Copper | 0.20 | 5.0 |
| Fluoride | 1.0 | 15.0 |
| Iron | 5.0 | 20.0 |
| Lead | 5.0 | 10.0 |
| Lithium | 2.5[b] | 2.5[b] |
| Manganese | 0.20 | 10.0 |
| Molybdenum | 0.010 | 0.050[c] |
| Nickel | 0.20 | 2.0 |
| Selenium | 0.020 | 0.020 |
| Zinc | 2.0 | 10.0 |

a. These levels will normally not adversely affect plants or soils. No data are available for mercury, silver, tin, titanium, tungsten.

b. Recommended maximum concentration for irrigating citrus is 0.075 mg/l.

c. For only acid fine-textured soils or acid soils with relatively high iron oxide contents.

### B.4.g. Bacteriological Quality

Microorganisms, primarily bacteria, are normally present in large quantities in wastewater. The bulk of these microorganisms can be removed by conventional treatment, and the soil mantle is quite efficient in the removal of bacteria and probably viruses through the processes of filtration and adsorption [40, 43, 44, 77, 78, 143]. Problems may arise, however, in the actual application process, especially in spraying, where aerosols could present a health hazard (I-F.2.d.). High degrees of preapplication treatment, including disinfection, may be necessary, particularly in cases in which public access to the application area is allowed.

### B.4.h. Projected Changes

The possibility of changes in wastewater characteristics should be investigated, both from the standpoint of projected future permanent changes and seasonal variations. Changes in characteristics may reflect those in water supply and local industries. Seasonal variations may be the result of variations in water-supply characteristics, domestic use, industrial use, and population fluctuations. Adverse changes in wastewater mineral quality may require selection of alternate crops or changes in loading rates.

### B.4.i. Industrial Components

Industrial components often present in municipal wastewater normally require special consideration because of the occurrence of abnormal concentrations of certain constituents and their influence on the overall wastewater characteristics. Industries that discharge wastewater into municipal systems should be studied on the basis of: existing concentrations, seasonal variations, and expected changes in the plant process which might affect wastewater characteristics. Industrial wastewater ordinances, generally designed to prevent discharge to sewers of elements and compounds in concentrations toxic to microorganisms, should be analyzed with regard to limiting the discharge of materials such as sodium or boron which may be toxic to plants. Reference should be made to the Pretreatment Standards (40 CFR 128).

### B.4.j. BPT Constituents

The proposed BPT document [3] presents information and criteria on waste management alternatives for achieving best practicable treatment including land application, treatment and discharge, and reuse systems. Where land application systems discharge to surface waters, the discharge quality criteria are the same as for the conventional methods. Where land-application effluents result in permanent groundwater, the BPT document sets forth guidelines for protection of the groundwater quality which include chemical, pesticide, and bacteriological constituents. These guidelines should be consulted for limitations on any constituents not discussed previously in this section.

## Section C

## EVALUATION OF POTENTIAL SITES

The process of site selection for land-application systems should include an initial evaluation on the basis of criteria presented in this section. The environmental setting should be described and the individual site characteristics should be analyzed. Each site should then be reevaluated in light of considerations of treatment methods, design, and expected impacts.

### C.1. GENERAL DESCRIPTION

A preliminary step in site evaluation should be a general description of the land involved. The environmental setting should be described with emphasis on:

- The location of the site
- The relationship to the overall land-use plan
- The proximity to surface water
- The number and size of available land parcels
- Location and use of any existing potable wells (I-C.2.e.6).

### C.1.a. Location

The description of site location should include both the distance and elevation difference from the treatment plant or wastewater collection area. Both will affect the feasibility and economics of the transmission of the wastewater to the site. Any significant obstructions to transmission, such as rivers, freeways, or developed residential areas, should be noted.

### C.1.b. Compatibility with Overall Land-Use Plan

Of significant importance in site selection is the compatibility of the intended use with regional land-use plans. The regional planners or the planning commission should be consulted as to the future use of potential sites.

During a visit to the site, the current use, adjacent land use, and proximity to areas developed for residential, commercial, or recreational activities can be ascertained. On the basis of a review of master plans or discussions with local planners, the proposed future use, zoning, and proposed development of the adjacent area can be determined.

### C.1.c. Proximity to Surface Water

In many cases, the proximity of the potential site to a surface-water body may be of significance. For overland flow systems, and systems with underdrains or pumped withdrawal, discharge of renovated water to a surface-water body may be necessary. In such a case, the feasibility and cost of transmission may become important considerations. The relationship of surface water to the overall hydrology of the area, and particularly to the groundwater, should be evaluated. Water-quality aspects and site drainage are considered later in this section.

### C.1.d. Number and Size of Available Land Parcels

The relative availability of land at potential sites, together with the probable price per acre, must be defined early in the evaluation. The number and size of available parcels will be of significance, especially in relation to the complexity of land acquisition and control – a subject that is discussed at the end of this section.

## C.2. DESCRIPTION OF ENVIRONMENTAL CHARACTERISTICS

The environmental characteristics of a potential site that may affect the future selection of a land-application method and the subsequent design of the treatment system include: climate, topography, soil characteristics, geologic formations, groundwater, and receiving water. The degree of detail required for the evaluation of any one particular characteristic is highly variable and dependent upon the size of the project and the severity of local conditions. This discussion cannot cover all conceivable aspects, but the major environmental factors will be discussed.

### C.2.a. Climate

Local climatic conditions will affect a large number of design decisions including: the method of land application, storage requirements, total land requirements, and loading rates. The National Weather Service, local airports, and universities are potential sources of climatological data. The data base should encompass a long enough period of time so that long-term averages and frequencies of extreme conditions can be established. Each of the climatic factors is discussed in the following paragraphs.

C.2.a.1. Precipitation – Analysis of rainfall data should be conducted with respect to both quantities and seasonal distribution. Quantities should be expressed in terms of averages, maximums, and minimums for the period of record. A frequency analysis should be made to determine the design annual precipitation, which will normally be the maximum precipitation values having a return period of a given number of years (the wettest year in a given number of years). The plot of precipitation against return period on probability paper, a method commonly used to display the results of the frequency analysis, is illustrated in Figure 2. Different return periods may often be used for the determination of liquid loading rates (I-E. 1. a) and the determination of storage capacity (I-E. 4.).

In cold regions, an analysis of the snow conditions with respect to depth and period of snow cover may also be required. In most cases, except for some infiltration-percolation systems, periods of snow cover will necessitate storage of the effluent for later application.

C.2.a.2. Storm Intensities – An investigation of storm data for the period of record should be included in the precipitation study. A frequency analysis

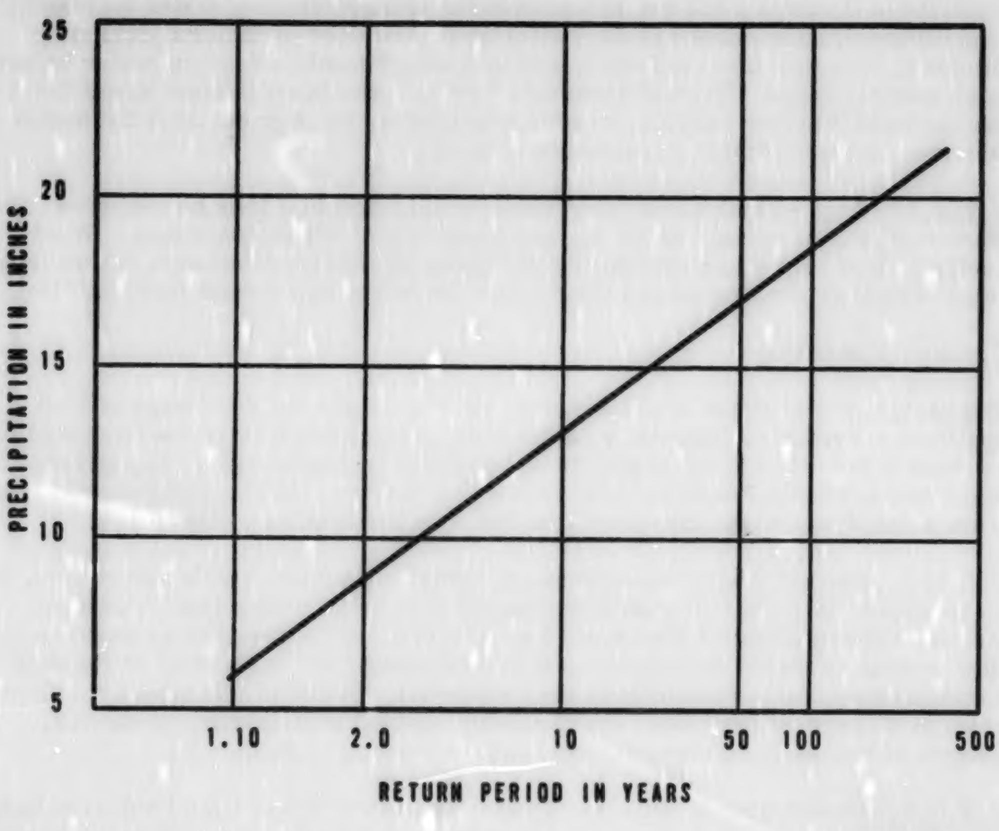


Figure 2. Typical frequency analysis for total annual precipitation

should be performed to determine the relationship between storm intensity, duration, and frequencies or return periods. The design storm event can then be analyzed for the amount of runoff it would produce and the need for any runoff control features can be determined.

**C.2.a.3. Temperature** – Temperature analysis should include the range of temperatures during the various seasons. Maximum periods of freezing conditions, particularly periods in which the ground is frozen, are of special interest in determining periods of inoperation. The effects of temperature are of importance in the selection of a land-application method, the design of the loading schedule, and in the determination of storage requirements. For irrigation of annual crops, the probable early and late season frost dates need to be determined.

**C.2.a.4. Evapotranspiration** – Evapotranspiration is the evaporation of water from the soil surface and vegetation plus the transpiration of water by plants. Evapotranspiration rates are dependent upon a number of factors, including humidity, temperature, and wind, and will significantly affect the water balance in almost all cases. Typical monthly totals are available in most areas from the National Weather Service, nearby reservoirs, the Agricultural Extension Service, or Agricultural Experiment Stations.

**C.2.a.5. Wind** – Analysis of wind velocity and direction may be required, and should contain seasonal variations and frequency of windy conditions. Wind analysis is of importance primarily for spray application systems, where windy conditions may require large buffer zones or temporary cessation of application.

## C.2.b. Topography

The topography of the site and adjacent land is critical to the design of land-application systems. Normally, a detailed topographic map of the area will be necessary for site selection and the subsequent system design. Topographic maps are available from the U.S. Geological Survey. Information to be gained from an analysis of the topography is listed in the following discussion.

**C.2.b.1. Ground Slope** – Ground slope, usually expressed as a percentage, is an important site characteristic for the determination of the land treatment method and application technique. For example, the success of an overland flow system is highly dependent upon ground slope, and irrigation by flooding normally requires slopes of less than 1 percent. Foliated hillsides with slopes of up to 40 percent have been sprayed successfully with effluent [140, 142]. Ranges of values for successful operation are given in Section D.

**C.2.b.2. Description of Adjacent Land** – The topography of land adjacent to the potential site should be included in the topographic evaluation. Of primary concern are the effects of storm runoff, both from adjacent land onto the site and from the site onto adjacent lands and surface water bodies. Also of concern will be areas downslope from the site where seeps may occur as a result of increased groundwater levels.

C.2.b.3. Erosion Potential – The erosion potential of the site and adjacent land should be predicted, and any required corrective action outlined. Both wastewater application rates and storm runoff should be considered. The typical Soil Conservation Service (SCS) evaluation of soils includes an analysis of erosion potential, which is valuable in determing the possible extent of the problem.

C.2.b.4. Flood Potential – The site topography should be evaluated and historical data reviewed to determine the possibility of flooding on the site or adjacent areas. Sites prone to flooding, such as flood plains, may still be suitable for land application but normally only if the physical equipment is protected and off-site storage is provided.

C.2.b.5. Extent of Clearing and Field Preparation Necessary – The extent of clearing and field preparation is largely dependent upon the selection of land-application method, the application technique, and the existing vegetation. Included in the evaluation should be:

- The extent of clearing of existing vegetation (if necessary)
- Disposition of cleared material
- Necessary replanting
- Earthwork required

Some of this information would be developed in detail in the environmental assessment.

### C.2.c. Soil Characteristics

Soil characteristics are often the most important factors in selection of both the site and the land-application method. Definite requirements for soil characteristics exist for each of the method alternatives, with overland flow and infiltration-percolation having the strictest requirements. Information on soil characteristics can be obtained from the Soil Conservation Service, many universities, and the Agricultural Extension Service.

C.2.c.1. Type and Description – The soil at the potential site should be described in terms of its physical and chemical characteristics. Important physical characteristics include texture and structure, which are largely influenced by the relative percentages of the mechanical, or particle-size, classes (gravel, sand, silt, and clay). Chemical characteristics which may be of importance are: pH, salinity, nutrient levels, and adsorption and fixation capabilities for various inorganic ions. The following series of tests is suggested:

- pH
- Salinity or electrical conductivity
- Organic matter
- Total exchangeable cations
- Levels of nitrogen, phosphorus, potassium, magnesium, calcium, and sodium
- Percent of the base exchange capacity occupied by sodium, potassium, magnesium, calcium, and hydrogen

Reference is suggested to the University of California manual for analysis of soils, plants, and waters [26].

C.2.c.2. Infiltration and Percolation Potential – The potential of the soil for both infiltration and percolation is of great importance in the site selection and selection of application method. Infiltration, the entry of water into the soil, is normally expressed as a rate in inches per hour. The rate generally decreases with wetting time and previous moisture content of the soil; consequently, it should be determined under conditions similar to those expected during operation. Percolation is the movement of water beneath the ground surface both vertically and horizontally, but above the water table. It is normally, dependent upon several factors, including soil type; constraints to movement, such as lenses of clay, hardpan, or rock; and degree of soil saturation. The limiting rate (either infiltration or percolation) must be determined and reported in inch/day (cm/day) or inch/week (cm/week).

The standard percolation test is not recommended for determination of infiltration or percolation rates. The test results are not reproducible by different fieldmen [182] and are affected by hole width, gravel packing of holes, depth of water in holes, and the method of digging the holes. More importantly, if subsurface lenses exist, the water in the test hole will move laterally, with the result being a fairly high percolation rate. Designing a liquid loading rate on that basis would be disasterous because, when the entire field is loaded, the only area for flow is the few feet of depth to the lens times the field perimeter. Instead of using the percolation test, it is suggested that several or more of the following approaches be used as a basis of determining infiltration and percolation rates: (1) consultation with Agriculture Extension Service agents, state or local government soil scientists, or independent soil specialists; (2) engineering analysis of several soil borings and soil classifications; (3) engineering analysis of soil profiles supplied by the Soil Conservation Service (SCS); (4) consultation with county agents, agronomists, or persons having farming experience with the same, similar, or nearby soils; and (5) experience from pilot studies on parts of the field to be used.

C.2.c.3. Soil Profile – The soil profile, or relation of soil characteristics to depth, will normally be required for all site evaluations. Generally, the profile should be determined to depths of 2 to 5 feet (0.61 to 1.52 m) for overland flow, at least 5 feet (1.52 m) for irrigation, and at least 10 feet (3.05 m) for infiltration-percolation. The underlying soil layers should be evaluated principally for their renovation and percolation potentials. Lenses or constraints to flow below these levels should be located.

C.2.c.4. Evaluation by Soil Specialists – In most cases, an evaluation by soil specialists will be necessary to determine the overall suitability of the soil characteristics for the intended use. SCS representatives, soil scientists, agronomists, and Agricultural Extension Service representatives are possible sources to be consulted.

### C.2.d. Geologic Formations

A basic description of the geologic conditions present and their effects should be required for all site evaluations. Infiltration-percolation sites and sites with suspected adverse geological conditions will require a relatively detailed analysis, while considerably less is required for most overland flow sites and many irrigation systems. Data on geological formations are available from the U.S. Geological Survey, state geology agencies, and occasionally from SCS or U.S. Bureau of Reclamation publications.

C.2.d.1. Type and Description – The geologic formations should be considered in terms of: the structure of the bedrock, the depth to bedrock, the lithology, degree of weathering, and the presence of any special conditions, such as glacial deposits. The presence of any discontinuities, such as sink holes, fractures or faults, which may provide short circuits to the groundwater, should be noted and thoroughly investigated. In addition, an evaluation of the potential of the area for earthquakes and their probable severity will often be of importance to the future design of the system.

C.2.d.2. Evaluation by Geologists – In many situations, an evaluation by a geologist or geohydrologist will be necessary. The geologist will be of value both in the investigation of the geologic conditions and in the evaluation of their effects. Of primary importance in the evaluation are the effects of the geology on the percolation of applied wastewater and the movement of groundwater.

### C.2.e. Groundwater

An investigation of groundwater must be conducted for each site, with particular detail for potential infiltration-percolation and irrigation sites. Evaluations should be made by the engineer to determine both the effect of groundwater levels on renovation capabilities and the effects of the applied wastewater on groundwater movement and quality with respect to the BPT requirements.

C.2.e.1. Depth to Groundwater – The depth to groundwater should be determined at each site, along with variations throughout the site, and seasonal variations. Depth to groundwater is important because it is a measure of the aeration zone in which renovation of applied wastewater takes place. Generally, the groundwater depth requirements are:

- Overland flow – sufficient depth not to interfere with plant growth
- Irrigation – at least 5 feet (1.52 m)
- Infiltration-percolation – preferably 15 feet (4.57 m) or more

Lesser depths may be acceptable where underdrains or pumped withdrawal systems are utilized.

When several layers of groundwater underlie a particular site, depths should be determined to each, unless they are separated by a continuous impervious stratum. The quality and current and planned use of each layer should also be determined.

C.2.e.2. Groundwater Flow – In most cases, the groundwater should be evaluated for direction and rate of flow and for the permeability of the aquifer. This evaluation may be unnecessary when percolation is minimal, as with an overland flow and some irrigation systems. For systems designed for high percolation rates, effects on the groundwater flow must be predicted.

Additionally, data on aquifer permeability may be evaluated, together with groundwater depth data, to predict the extent of the recharge mound. The direction of flow is important to the design of the monitoring system and should be traced to determine whether the groundwater will come to the surface, be intercepted by a surface water, or join another aquifer.

C.2.e.3. Perched Water – Perched water tables are the result of impermeable or semipermeable layers of rock, clay, or hardpan above the normal water table and may be seasonal or permanent. Perched water can cause problems for land-application systems by reducing the effective renovative depth. Sites should be investigated both for existing perched water tables and for the potential for development of new ones resulting from percolating wastewater. The effect of perched water tables should be evaluated, and the possibility of using underdrains investigated. A distinction should be made between permanent groundwater protected by impermeable strata and perched groundwater above such strata.

C.2.e.4. Quality Compared to Requirements – The quality of the groundwater is of great interest, especially in cases in which it is used for beneficial purposes or differs substantially from the expected quality of the renovated wastewater. The existing quality should be determined and compared to quality requirements for its current or intended use. The proposed requirements for BPT [3] include limitations for chemical constituents, pesticide levels, and bacteriological quality as discussed in I-B.4.

C.2.e.5. Current and Planned Use — Both current and planned use of the groundwater should be determined, and the quality requirements for the various uses detailed. The distance from the site to the use areas may also be of importance, because further renovation may occur during lateral movement.

C.2.e.6. Location of Existing Wells — Much of the data required for groundwater evaluation may be determined through use of existing wells. Wells that could be used for monitoring should be listed and their relative location described. Historical data on quality, water levels, and quantities pumped that may be available from the operation of existing wells may be of value. Such data might include seasonal groundwater-level variations, as well as variations over a period of years. Logs containing soil data may be available from the drillers of these wells, and this information could augment data from soil borings or geological maps. It should be noted that much information on private wells can be obtained only with the owner's consent. Determining ownership and locating owners can be difficult and time-consuming.

### C.2.f. Receiving Water (Other than Groundwater)

Land-application systems in which renovated water is recovered, particularly overland flow systems, may require discharge into a receiving surface water body. Such a discharge would require a permit under the National Pollution Discharge Elimination System (NPDES). If the receiving water is designated as effluent limited, the requirements for secondary treatment apply. If the receiving water is designated as water-quality limited, pursuant to Section 303 of P.L. 92-500, treatment must be provided consistent with the established water-quality standards. Included in the evaluation should be descriptions of: the type of body (lake, stream, etc.), its current use and water quality, prescribed water-quality standards and effluent limitations, and water-rights considerations. Special water-quality requirements and other considerations may exist when the potential receiving water is an intermittent stream. The current use of the water, together with its prescribed water-quality standards, will determine the degree of treatment necessary by the land-application system.

Water-rights considerations may require that certain quantities of renovated water be returned to a particular water body, particularly in the western states. In cases in which a change in method of disposal or point of discharge is contemplated, the state agency of other cognizant authority should be contacted, and the status of all existing water rights thoroughly investigated.

## C.3. METHODS OF LAND ACQUISITION OR CONTROL

After potential sites have been selected, alternative methods of land acquisition or control should be assessed. Alternative methods include: (1) outright purchase of land with direct control, (2) appropriate lease of land with direct control, (3) purchase of land with lease back to farmer for the purpose of land application, and (4) contract with user of wastewater. An appropriate lease would be one in which the investment of funds for construction of the land-application system would be protected and direct control of the effluent application would be retained by the municipality or district.

The selection of an acquisition and control method is highly dependent on the selected method of application. Infiltration-percolation and overland flow systems normally require a high degree of control and may often be suitable only if outright purchase of the land is possible. Because land control requirements are more flexible for irrigation systems, the leasing of land to agricultural users may be possible. Leasing of required land is often best suited to pilot studies and temporary systems.

Grant eligibility has not been considered in the discussion of these methods. For land acquisition to be eligible for a construction grant, under P. L. 92-500, the land must be an integral part of the treatment process or is to be used for ultimate disposal of residues resulting from such treatment.

## Section D

## CONSIDERATION OF LAND-APPLICATION ALTERNATIVES

On the basis of the project objectives and the characteristics of the selected potential sites, various methods of land application should be considered. Alternatives can be classified into three main groups: irrigation, infiltration-percolation, and overland flow or spray-runoff. These alternatives differ considerably, with respect to both use for different objectives and requirements for site characteristics. Each method is shown schematically in Figure 3. The various possible uses for land-application approaches following some initial treatment are compared in Table 4. These objectives should then be related to the project objectives (I-A). Site characteristics discussed in the previous section that affect alternative selection will be briefly related to each of the three alternatives in the following presentation.

Table 4. COMPARISON OF IRRIGATION, OVERLAND FLOW, AND INFILTRATION-PERCOLATION OF MUNICIPAL WASTEWATER

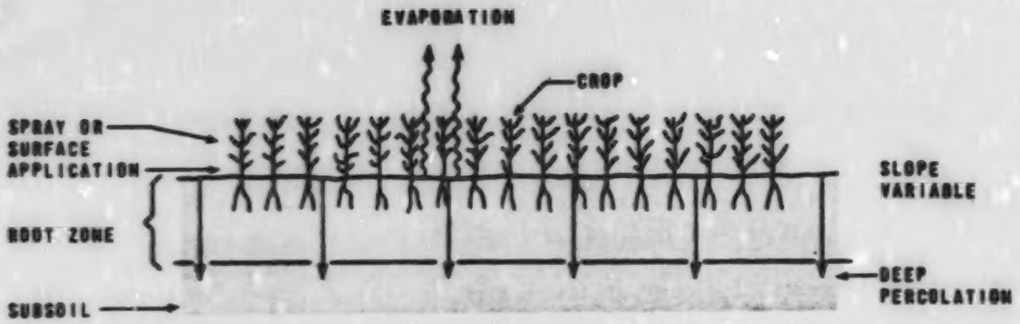
| | Type of approach | | |
|---|---|---|---|
| Objective | Irrigation | Overland flow | Infiltration-percolation |
| Use as a treatment process with a recovery of renovated water[a] | 0-70% recovery | 50 to 80% recovery | Up to 97% recovery |
| Use for treatment beyond secondary: | | | |
| 1. For $BOD_5$ and suspended solids removal | 98+% | 92+% | 85-99% |
| 2. For nitrogen removal | 85+%[b] | 70-90% | 0-50% |
| 3. For phosphorus removal | 80-99% | 40-80% | 60-95% |
| Use to grow crops for sale | Excellent | Fair | Poor |
| Use as direct recycle to the land | Complete | Partial | Complete |
| Use to recharge groundwater | 0-70% | 0-10% | Up to 97% |
| Use in cold climates | Fair[c] | - -[d] | Excellent |

a. Percentage of applied water recovered depends upon recovery technique and the climate.

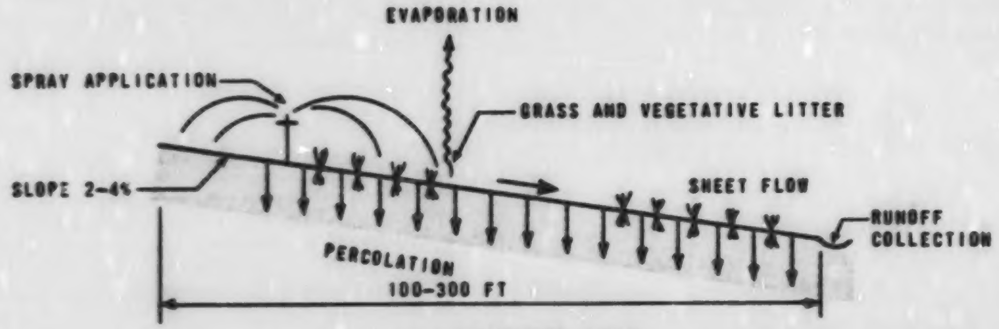
b. Dependent upon crop uptake.

c. Conflicting data--woods irrigation acceptable, cropland irrigation marginal.

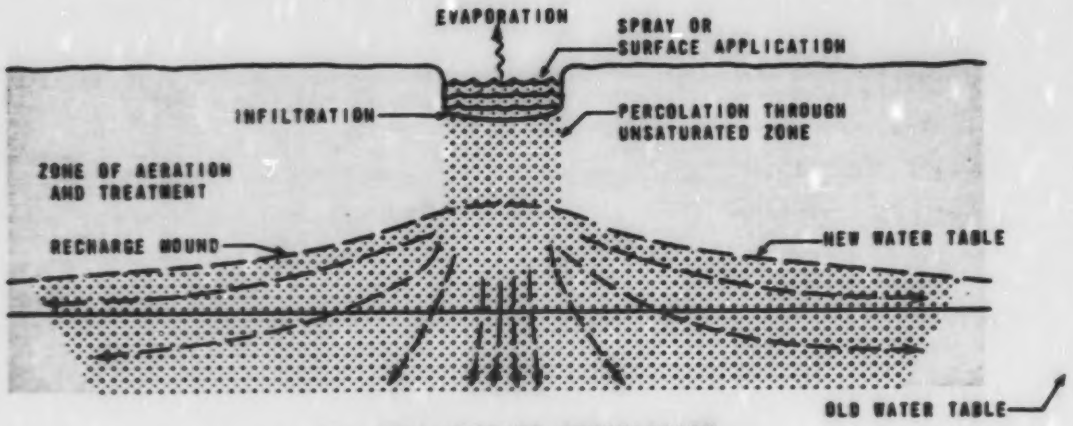
d. Insufficient data.


EVAPORATION
CROP
SPRAY OR SURFACE APPLICATION
SLOPE VARIABLE
ROOT ZONE
DEEP PERCOLATION
SUBSOIL

(a) IRRIGATION


EVAPORATION
SPRAY APPLICATION
GRASS AND VEGETATIVE LITTER
SLOPE 2-4%
SHEET FLOW
RUNOFF COLLECTION
PERCOLATION
100-300 FT

(b) OVERLAND FLOW


EVAPORATION
SPRAY OR SURFACE APPLICATION
INFILTRATION
PERCOLATION THROUGH UNSATURATED ZONE
ZONE OF AERATION AND TREATMENT
RECHARGE MOUND
NEW WATER TABLE
OLD WATER TABLE

(c) INFILTRATION-PERCOLATION

Figure 3. Methods of land application

## D. 1. IRRIGATION

The most common method of treatment by land application is irrigation. It is the controlled discharge of effluent, by spraying or surface spreading, onto land to support plant growth. The wastewater is "lost" to plant uptake, to air by evapotranspiration, and to groundwater by percolation. Liquid loading rates up to 4 inches (10.2 cm) per week on a seasonal basis and 8 feet (2.44 m) per year on an annual basis are in this category. Systems with liquid loading rates exceeding these (other than overland flow) are normally considered to be of the infiltration-percolation type.

The range of suitable site characteristics for irrigation systems is wide. The major criteria generally considered preferable are as follows:

- Climate – warm-to-arid climates are preferable, but more severe climates are acceptable if adequate storage is provided for wet or freezing conditions.
- Topography – slopes up to 15 percent for crop irrigation are acceptable provided runoff or erosion is controlled.
- Soil type – loamy soils are preferable, but most soils from sandy loams to clay loams are suitable.
- Soil drainage – well-drained soil is preferable, however, more poorly drained soils may be suitable if drainage features are included in the design.
- Soil depth – uniformly 5 to 6 feet (1.52 to 1.83 m) or more throughout sites is preferred for root development and wastewater renovation.
- Geologic formations – lack of major discontinuities that provide short circuits to the groundwater is necessary.
- Groundwater – minimum depth of 5 feet (1.52 m) to groundwater is normally necessary to maintain aerobic conditions, provide necessary renovation, and prevent surface waterlogging. May be obtained by underdrains or groundwater pumping.

### D. 1. a. Purpose of Irrigation

The suitability of a particular site, a particular effluent, and the future design of the system will depend, to a large degree, on the intended purpose of irrigation. Three distinct purposes have been identified.

- Optimization of crop yields
- Maximization of effluent application
- Landscape irrigation

Each purpose is defined and major design considerations are introduced in the material that follows:

D.1.a.1. Optimization of Crop Yields – Irrigation systems designed for this purpose are often used in situations in which effluent is offered to farmers for their own use. The application rate for the effluent is based only on the needs of the crop; normally, no more effluent is applied than is necessary for optimum crop yield. Relatively wide variations in application rates usually occur as a result of seasonal variations in crop moisture demand and seasonal precipitation. Consequently, total land and storage requirements may be relatively high. Operation without purchase of land for irrigation may be possible through contracts with users of the wastewater.

D.1.a.2. Maximization of Effluent Application – In irrigation systems designed for maximum effluent application, considerably higher loading rates may be used than are required for crop growth. Crops of lesser economic value may be chosen on the basis of their water tolerance, nutrient uptake, or tolerance to certain wastewater constituents. Greater amounts of percolation may also be planned for, as design liquid loading rates will exceed the plant requirements.

Forestland irrigation systems can also be designed for maximum effluent application. The greater suitability of forestland to cold-weather operation may result in a more evenly distributed loading schedule and can reduce storage requirements. However, the long-range nutrient removal capabilities of forest systems are generally less than for most field crops.

Forestland irrigation can result in the succession of water-tolerance species in place of naturally occurring vegetation. This occurrence should be considered in the environmental assessment.

D.1.a.3. Landscape Irrigation – Irrigation of turf, especially in recreational areas, such as parks and golf courses, requires special consideration. The condition of the turf is normally of primary importance, and application rates must be adjusted for this purpose. Public health considerations are also of great importance, with high degrees of treatment prior to application, including disinfection, normally being required. Additional measures, such as irrigation during off-hours, are often necessary.

### D. 1. b. Application Techniques

Three application techniques are employed in irrigation systems (Figure 4):

- Spraying
- Ridge and furrow
- Flooding

Topography, soil conditions, weather conditions, agricultural practice, and economics are factors to be considered in technique selection. General design features for each technique are described in reference [125, 184].

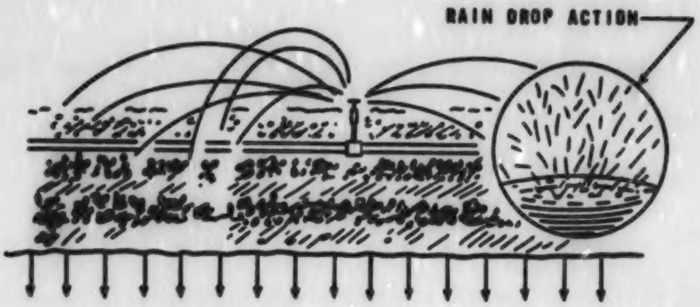
D. 1. b. 1. Spraying – Spraying involves the application of effluent above the ground either through nozzles or sprinkler heads. Other elements of the system include: pumps or a source of pressure, supply mains, laterals, and risers. Design of a system can be quite variable; it can be portable or permanent, moving or stationary. Spray systems are the most efficient for uniform flow distribution, but such systems are also generally the most expensive. High wind, a problem common to spray irrigation systems, adversely affects efficiency of distribution and can also spread aerosol mists. Hydraulic design factors for spraying systems are included in references [114, 115, 155].

D. 1. b. 2 Ridge and Furrow – Ridge and furrow irrigation is accomplished by gravity flow of effluent through furrows, from which it seeps into the ground. Utilization of this technique is generally restricted to relatively flat land, and extensive preparation of the ground is required. The operating cost is relatively low, and the technique is well suited to certain row crops. Uniformity of distribution, however, is fairly difficult to maintain unless the grading of the land is nearly perfect [184].

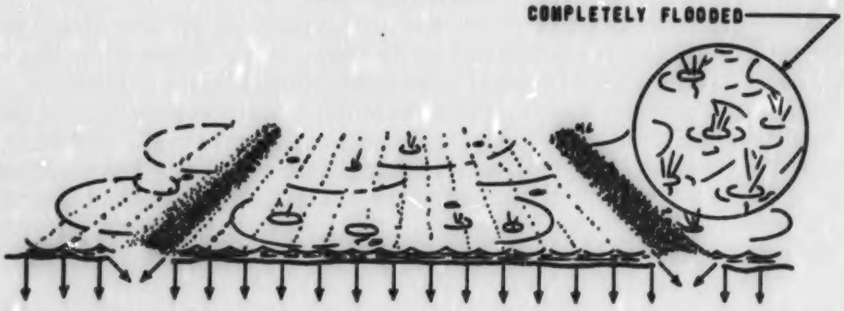
D. 1. b. 3. Flooding – Irrigation by flooding is accomplished by inundation of the land with several inches of effluent. Descriptions of the various flooding techniques are contained in Wastewater Treatment and Reuse by Land Application [125]. The choice of crop is critical because it must be able to withstand periods of inundation with the technique. The depth of applied effluent and period of flooding are dependent upon the characteristics of the soil and the crop grown.

### D. 2. INFILTRATION-PERCOLATION

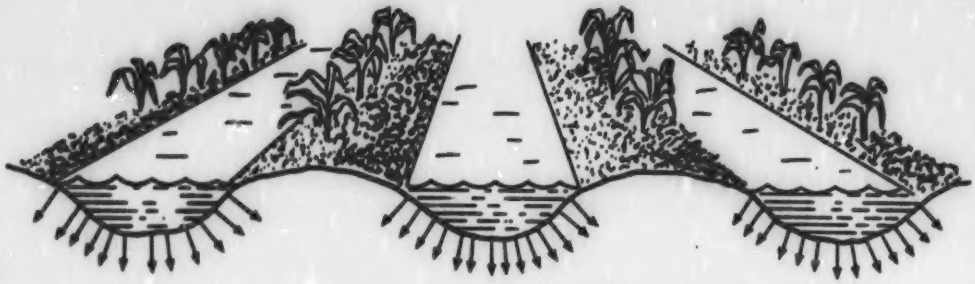
In this form of treatment, wastewater may be applied to the soil by spreading or spraying. Renovation is achieved as the effluent travels through the soil matrix by natural physical, chemical, and biological processes. Effluent is allowed to infiltrate at a relatively high rate, and consequently less land is required for the same volume than for the two other alternatives. The major


RAIN DROP ACTION

(a) SPRINKLER


COMPLETELY FLOODED

(b) FLOODING



(c) RIDGE AND FURROW

Figure 4. Irrigation techniques

portion of the wastewater percolates to the groundwater, while most of the remainder is lost through evaporation.

Important criteria for site selection include: geologic conditions, soil conditions, and groundwater depth and movement. Because of the high rates of loading, the geologic conditions and status of the groundwater are relatively more important than in irrigation or overland flow systems.

Thomas recommends that a depth of 15 feet (4.55 m) from the surface to the natural groundwater be considered a minimum [166], and Bouwer recommends that the groundwater recharge mound should not be allowed to rise closer to the soil surface than a distance of about 4 feet (1.22 m) [19]. Lesser depths may be suitable under special conditions; however, a lesser degree of renovation becomes much more probable. The use of an artificial drainage system, such as pumped withdrawal, should be considered as a means for increasing groundwater depths.

Well-drained soil is critical to the success of an infiltration-percolation system. Acceptable soils include sand, sandy loams, loamy sands, and gravels. Very coarse sand and gravel are not ideal because they allow wastewater to pass too rapidly through the first few feet where the major biological and chemical action takes place [125]. Consideration should be given to the infiltration surface, which may be planted, overlain with graded sand or gravel, or left plain. Seasonal variations in temperature and precipitation should also be considered in determining application rates.

### D.2.a. Purpose of Infiltration-Percolation

Wastewater treatment systems employing infiltration-percolation may be designed for three purposes: groundwater recharge; recovery of renovated water, using wells or underdrains; and interception of renovated water by a surface water body.

D.2.a.1. Groundwater Recharge — In systems designed for this purpose, all of the infiltrated wastewater is allowed to percolate directly to the groundwater. A mound in the water table will be created under the infiltration area, consequently reducing the renovative distance. Groundwater recharge may be used for improving poor groundwater quality, for limiting salt-water intrusion, or merely as an efficient method for treatment and disposal of wastewater.

For the renovated water, the quality requirements for groundwater are given in the BPT document [3]. The potential for meeting these guidelines depends upon the soil characteristics, loading rates and cycles, management techniques, and wastewater characteristics (I-B.4).

D.2.a.2. Pumped Withdrawal — In cases in which the BPT requirements cannot be met or the groundwater is of poor quality, renovated water may be directly withdrawn from the zone of saturation for reuse. Additionally, pumping from wells, or a system of underdrains, can be used to reduce the extent of the recharge mound in the water table, thereby increasing renovation distance.

D. 2. a. 3. Interception by Surface Water – Infiltration-percolation systems may be designed for situations in which the renovated water moves vertically and laterally and is subsequently intercepted by a surface water body. This constitutes an indirect discharge to the surface water body.

### D. 2. b. Application Techniques

Spreading and spraying are two application techniques that are suitable for infiltration-percolation. Factors which should be considered in the selection of the application technique include: soil conditions, topography, climate, and economics.

D. 2. b. 1. Spreading – Infiltration-percolation by means of spreading is perhaps the simplest of the land-application techniques. It is also the technique least affected by cold or wet weather. Several basins are normally used and periods of flooding are alternated with periods of drying. Application using the ridge and furrow technique has also been accomplished [125].

D. 2. b. 2. Spraying – Application of effluent at high rates employing spraying has been accomplished. High-rate spray irrigation systems, where the loading rate exceeds 4 inches (10.2 cm) per week, are included in this category. Normally, vegetation is necessary to protect the surface of the soil and to preclude runoff. Hydrophytic or water-tolerant grasses are usually chosen. Spraying of forestland may also be considered for infiltration-percolation.

## D. 3. OVERLAND FLOW

Wastewater treatment by this method has been practiced primarily by food-processing industries, but it appears quite suitable, under certain conditions, for municipal wastewater. It is nevertheless still in the experimental stage with regard to municipal systems in this country at this time.

Renovation is accomplished by physical, chemical, and biological means as wastewater flows through vegetation on a sloped surface. Wastewater is sprayed over the upper reaches of the slopes and a high percentage of the treated water is collected as runoff at the bottom of the slope, with the remainder being lost to evapotranspiration and percolation. Important criteria for site selection include: soil conditions, topography, and climate; with the most important being soil conditions. Soils with minimal infiltration capacity, such as heavy clays, clay loams, or soils underlain by impermeable lenses, are required for this method to be effective. Soils with good drainage characteristics are best suited for other land-application methods [125].

A mantle of 6 to 8 inches (15.2 to 20.3 cm) of good topsoil is recommended [130]. A sloping terrain is necessary to allow the applied wastewater to flow slowly over the soil surface to the runoff collection system. Slope distance is a function of the spray diameter, loading rate, and degree of renovation required. The degree of slope depends on the existing topography and the economics of earthwork; however, slopes of 2 to 4 percent are preferred.

### D.3.a. Purpose of Overland Flow

The purpose of the overland flow system, and the intended disposition of its renovated water, will affect both the site selection and the design of the system.

D.3.a.1. Discharge to Surface Waters — Collected runoff from most overland flow systems is discharged to surface waters. Renovated water is collected at the toe of the slope in cutoff ditches or by similar means and channeled to a monitoring point before being discharged. The proximity of the site to a receiving water body and the method of transmission of renovated water to the discharge point should be considered in the design of such a system.

For a surface water discharge the renovated water must meet the minimum of secondary treatment requirements or effluent limitations based on water-quality standards. As shown in Tables 4 and 12 (II-D), the system is capable of a high degree of treatment. To meet the fecal coliform standards, however, disinfection of the collected water may be necessary.

D.3.a.2. Reuse of Collected Runoff — Although largely untried, treated water from overland flow may be utilized by industry for irrigation or in recreational impoundments. Storage may be necessary if continuous use is not possible. Overland flow systems designed for this purpose may be desirable in certain water-short areas and at sites where transmission of runoff to a receiving surface water body is impractical or uneconomical.

### D.3.b. Application Techniques

Spraying is the application technique used most commonly for overland flow systems. Flooding between borders has been used in Melbourne, Australia [76] but only for 6 months of the year. Factors that should be considered in the selection of the application technique include: topography, suspended solids in the wastewater, agricultural practices, and economics.

D.3.b.1. Spraying — Spraying is the only application technique presently practiced in this country. Wastewater is applied on the upper reaches of the slope and is allowed to flow downhill. Spraying may be accomplished by means of fixed sprinklers or rotating boom-type sprays.

D.3.b.2. Flooding — Application by flooding or other surface techniques in overland flow systems has not been demonstrated in this country, but it has been practiced successfully in Melbourne, Australia. If high concentrations of suspended solids are present, settling in the upper reaches may cause an odor problem. Because uniform distribution is critical, flooding may not be successful unless care is taken to produce an extremely smooth terrace with no cross slope.

## D.4. COMBINATIONS OF TREATMENT TECHNIQUES

Wastewater treatment systems must often be designed to meet a wide variety of demands under an equally wide variety of conditions. Land application offers possibilities of various combinations of techniques that may be useful in the solution of a particular treatment problem. Combinations may include either several land-application techniques or land application together with in-plant treatment. Increased felxibility of the overall system and increased complexity of operation are side effects of treatment combinations which should be considered.

### D.4.a. Combinations of Land-Application Techniques

Combinations of land-application techniques may be desirable when dealing with problems of differences in site characteristics (either within one large site or between a number of sites), seasonal weather variations, or impact minimization on a particular area. They may also be useful in adapting land application to present land use; for instance, using a portion of the wastewater to irrigate an existing golf course.

### D.4.b. Combinations with In-Plant Treatment

Combinations of land application with in-plant treatment and receiving water discharge may be advantageous in certain situations, especially if operating costs of in-plant treatment are high. The most obvious advantages of this type of combination can be seen in cold-weather regions where large storage requirements may make land application an undesirable alternative. Partial in-plant treatment could be used prior to land application in summer months, with full in-plant treatment and surface water discharge used in the winter months [130]. Combinations for other purposes may be worth investigating. Stormwater storage or treatment systems may also be integrated into combined wastewater management systems.

## D.5. COMPATIBILITY WITH SITE CHARACTERISTICS

The success of a land-application system will depend upon the compatibility of the selected treatment alternative to the project objectives, climate, and site characteristics. To ensure compatibility, it is necessary to reevaluate the alternative selection by proceeding stepwise through the flow chart. (Figure 1 in the Introduction), reviewing each consideration.

## Section E

## DESIGN CONSIDERATIONS

Design considerations will differ greatly depending on whether irrigation, infiltration-percolation, or overland flow is selected. The major considerations, which are discussed in this section, include:

- Loading rates
- Land requirements
- Crop selection
- Storage requirements
- Preapplication treatment requirements
- Management considerations
- Flexibility
- Design reliability

The key issues involved in delineation of these design factors are identified and discussed.

### E.1. LOADING RATES

To determine what characteristics of the wastewater will be limiting, balances should be made for water, nitrogen, phosphorus, organic matter, or other constituents of abnormally high concentration (as determined under I-B.4). On the basis of those balances, a loading rate can be established for each parameter. Each loading rate should then be used in calculating the required land area and the critical loading rate is the one requiring the largest field area.

#### E.1.a. Liquid Loading/Water Balance

The elements considered in a water balance are:

- Effluent applied
- Precipitation
- Evapotranspiration

- Percolation

- Runoff

The interrelationships between the elements of the water balance for irrigation, infiltration-percolation, and overland flow are discussed in the following subsections.

Irrigation – For irrigation systems, the amount of effluent applied plus precipitation should equal the evapotranspiration plus a limited amount of percolation. In most cases, surface runoff from fields irrigated with municipal effluent will not be allowed or must be controlled. The water balance will be:

$$\text{Design precipitation} + \text{Effluent applied} = \text{Evapotranspiration} + \text{Percolation} \qquad (2)$$

Seasonal variations in each of the above values should be taken into account. It is suggested that this be done by means of evaluating the water balance for each month as well as the annual balance. This method is illustrated in Example No. 1.

The value for design precipitation should be determined on the basis of a frequency analysis of wetter than normal years (I-C. 2. a. 1.). The wettest year in 10 is suggested as reasonable in most cases; however, it is prudent to check the water balance using the range of precipitation amounts that may be encountered. For purposes of evaluating monthly water balances, the design annual precipitation can often be distributed over the year by means of the average distribution, which is the average percentage of the total annual precipitation that occurs in each month. Again, the range of monthly values that may be encountered should be analyzed, especially for the months when the storage reservoir is full.

Evapotranspiration will also vary from month to month, however, the total for the year should be relatively constant. The amount of water lost to evapotranspiration each month should be entered in Equation 2.

Percolation includes that portion of the water, which after infiltration into the soil, flows through the root zone and eventually becomes part of the groundwater. The percolation rate used in the design should be determined on the basis of a number of factors (I-C. 2. c. 2.) including: soil characteristics, underlying geologic conditions, groundwater conditions, and the length of drying period required for satisfactory crop growth and wastewater renovation. The actual percolation rate will vary with soil temperature throughout the year; however, for design purposes, it is often possible to assume a constant rate.

When irrigating in arid climates, it is necessary to remove the salts that accumulate in the root zone as a result of evaporation. Some amount of percolation is necessary to accomplish this leaching. Ayers [7] has calculated the leaching requirements for various crops, depending upon crop tolerances (I-E. 3.) and total dissolved solids in the effluent. King and Hanks [75] have investigated the possibility of controlling the quality of return flows by varying the timing of irrigation applications and have developed a mathematical model that may prove valuable for situations in which TDS control is necessary.

### EXAMPLE No. 1 – Determine the water balance for an irrigation system.

Assumptions

1. The design precipitation is for the wettest year in 10, with average monthly distribution.
2. Average monthly evapotranspiration rates are used; these are derived from the Agricultural Extension Service.
3. The site is mostly flat and level.
4. The soil is a deep sandy loam.
5. The crop is coastal Bermuda grass.
6. Storage will be provided for a portion of the flow during the winter.
7. Runoff, if any, will be collected and stored for reapplication.

Solution – Computations and results are presented in Table 5.

1. From a curve similar to Figure 2, the design annual precipitation for the wettest year in 10 is found to be 13 in. (33.0 cm). The precipitation is distributed over the year on the basis of average distribution and entered into Column 5 in Table 5.
2. Average monthly evapotranspiration rates are entered into Table 5 in Column 2.
3. On the basis of soil and geological evaluations, the design percolation rate is determined to be 10 in./mo (25 cm/mo) and entered into Column 3. The total water losses are determined by adding Columns 2 and 3 and entering the sum in Column 4.
4. Using Equation 2, the design precipitation is subtracted from the total water losses to determine the amount of effluent to be applied (Column 6).

## Table 5. WATER BALANCE FOR EXAMPLE NO. 1

| Month (1) | Water losses: Evapo-transpiration, in. (2) | Water losses: Percolation, in. (3) | Water losses: Total, in. (2) + (3) = (4) | Water applied: Precipitation, in. (5) | Water applied: Effluent applied, in. (4) - (5) = (6) | Water applied: Total, in. (5) + (6) = (7) |
|---|---|---|---|---|---|---|
| Jan | 0.7 | 10.0 | 10.7 | 2.3 | 8.4 | 10.7 |
| Feb | 1.5 | 10.0 | 11.5 | 2.3 | 9.2 | 11.5 |
| Mar | 3.1 | 10.0 | 13.1 | 2.1 | 11.0 | 13.1 |
| Apr | 3.9 | 10.0 | 13.9 | 1.6 | 12.3 | 13.9 |
| May | 5.2 | 10.0 | 15.2 | 0.4 | 14.8 | 15.2 |
| Jun | 6.5 | 10.0 | 16.5 | 0.2 | 16.3 | 16.5 |
| Jul | 7.0 | 10.0 | 17.0 | 0.1 | 16.9 | 17.0 |
| Aug | 6.5 | 10.0 | 16.5 | Trace | 16.5 | 16.5 |
| Sep | 4.4 | 10.0 | 14.4 | 0.2 | 14.2 | 14.4 |
| Oct | 3.9 | 10.0 | 13.9 | 0.6 | 13.3 | 13.9 |
| Nov | 1.5 | 10.0 | 11.5 | 1.0 | 10.5 | 11.5 |
| Dec | 0.8 | 10.0 | 10.8 | 2.2 | 8.6 | 10.8 |
| Total annual | 45.0 | 120.0 | 165.0 | 13.0 | 152.0 | 165.0 |

Note: 1 inch = 2.54 cm

### Comments

1. The maximum application of effluent will be less than 4 in./wk (10 cm/wk) and will occur in July.
2. If the effluent available equals effluent applied on a yearly basis, then 152 in./yr divided by 12 months/yr equals 12.7 inches of effluent would be available each month (see Example No. 3).
3. Storage would be required for a portion of the flow for each month in which the effluent available exceeded the effluent applied. In this case, storage would be required from approximately mid November to mid April.
4. The annual liquid loading of 152 inches (386 cm) would place this land-application system above the normal loading range for irrigation of 24 to 96 in./yr (61 to 244 cm/yr).
5. The results obtained from this process would be utilized in the determination of land requirements (I-E.2.) and storage requirements (I-E.4.).

Infiltration-Percolation — The elements of the water balance for infiltration-percolation systems are the same as for irrigation (see Equation 2). Direct runoff is not designed into such systems.

For low-rate applications involving evaporation-percolation ponds, evaporation from the pond surface will be a significant factor. For these systems, the applied effluent should balance the net evaporation (total evaporation minus precipitation) plus the estimated percolation rate under saturated conditions. Saturated conditions should be used because normally the soil surface is constantly inundated, and the infiltration rate becomes significantly reduced over time. This reduced infiltration rate subsequently limits the movement of water through the soil.

For higher rate systems and systems with intermittent applications, percolation is the major factor, with evaporation accounting for 10 percent or less of the effluent applied. Precipitation is significant in humid climates and is analyzed in the same manner as irrigation, using a frequency analysis of the available data. In arid climates, the precipitation should not be omitted, because it often all occurs in a few winter months.

Overland Flow — Typical loading rates range from 0.25 to 0.7 in./day (0.64 to 1.78 cm/day) [125]. For year-round operation, the corresponding amount of effluent applied would range from 8 to 20 ft/yr (2.44 m to 6.10 m/yr). The water balance should be made mainly to determine the amount of runoff to be expected. The water balance equation for overland flow is:

$$\begin{matrix}\text{Design}\\\text{precipitation}\end{matrix} + \begin{matrix}\text{Effluent}\\\text{applied}\end{matrix} = \begin{matrix}\text{Evapo-}\\\text{transpiration}\end{matrix} + \text{Percolation} + \text{Runoff} \qquad (3)$$

Design precipitation and evapotranspiration values are determined in the same manner as for irrigation systems. Losses to percolation will generally be in the order of 0.1 in./day (0.3 cm/day) or less. Percolation rates should be estimated under saturated or nearly saturated conditions. The runoff rate can be determined as the known values are entered into Equation 3. A typical range of runoff values is from 40 percent (of the applied effluent plus precipitation) in the summer to 80 percent in the winter [32, 56, 85].

### E.1.b. Nitrogen Mass Balance

A total nitrogen balance is almost as important as a water balance, because nitrate ions are mobile in the soil and can affect the quality of the receiving water. On an annual basis, the applied nitrogen must be accounted for in crop uptake, denitrification, volatilization, addition to groundwater or surface water, or storage in the soil.

E. 1. b. 1. Total Annual Load – The total nitrogen load is necessary because all forms – organic, ammonia, nitrate, and nitrite – interact in the soil. The total nitrogen loading will be:

$$N = 2.7CL \qquad (4)$$

where

$N$ = annual nitrogen loading, lb/acre/yr
$C$ = total nitrogen concentration, mg/l
$L$ = annual liquid loading, ft/yr

or:

$$N = 0.1CL \qquad (5)$$

where

$N$ = annual nitrogen loading kg/ha/yr
$C$ = total nitrogen concentration, mg/l
$L$ = annual liquid loading, cm/yr

E. 1. b. 2. Total Annual Crop Uptake – The nitrogen uptake of most crops has been determined from greenhouse and field studies using fresh water for irrigation. Typical uptake values are given in Table 6. It should be noted that nitrogen uptake values may be higher when wastewater is applied instead of fresh water only because more nitrogen is available.

For land-application systems, few nitrogen uptake values for crops currently exist. It is expected that definitive values will be established in the near future. Nitrogen uptakes for plants not listed in Table 6 can generally be obtained from Agricultural Extension Service agents.

When more than one crop per year is grown on one field, the total nitrogen uptake for the entire year should be determined. Nitrogen removal by crop uptake is a function of crop yield and requires the harvesting and physical removal of the crop to be effective.

E. 1. b. 3. Denitrification and Volatilization – The extent of denitrification and volatilization depends on the loading rate and characteristics of the wastewater to be applied, and the microbiological conditions in the active zones of the soil.

Volatilization of ammonia will not be significant for effluents with a pH less than 7 or for nitrified effluents. For irrigation systems, denitrification is generally

### Table 6. TYPICAL VALUES OF CROP UPTAKES OF NITROGEN

| Crop | Nitrogen uptake, lb/acre/yr | References |
|---|---|---|
| Alfalfa | 155-220 | 54 |
| Red clover | 77-126 | 54, 1 |
| Sweet clover | 158 | 1 |
| Coastal Bermuda grass | 480-600 | 127 |
| Corn | 155 | 54 |
| Cotton | 66-100 | 1, 30 |
| Fescue | 275 | 1 |
| Milo maize | 81 | 1 |
| Reed canary grass | 226-359 | 32, 1 |
| Soybeans | 94-113 | 54, 1 |
| Wheat | 50-76 | 54, 1 |

Note: 1 lb/acre/yr = 1.12 kg/ha/yr

of minor importance, depending upon the soil, the application rate, and the crop. Hunt [67] suggests that denitrification may be a significant nitrogen removal mechanism for overland flow systems because observed removals cannot be accounted for solely by crop uptake.

For high-rate infiltration-percolation systems, denitrification is the only significant mechanism of nitrogen removal from the system. By managing the hydraulic loading cycle to create alternately anaerobic and aerobic conditions, Bouwer [20] obtained up to 80-percent nitrogen removal as a combined result of ammonia adsorption and denitrification during most of the period of inundation. Over a 4-year period the calculated removal was 30 percent at a loading rate of 21,000 lb/acre/yr (23,450 kg/ha/yr). Without special management techniques, overall nitrogen removal may only be 10 percent or less [82, 97].

E.1.b.4. Addition to Groundwater or Surface Water — The soil mantle cannot hold nitrogen indefinitely, although organic nitrogen can be stored in the soil to a certain extent. The ammonium and organic nitrogen is ultimately converted to nitrate nitrogen, which can leach out of the soil. Unless nitrogen is taken up by crops and physically removed by harvesting, or the nitrates are converted to nitrogen gas by denitrification, the nitrogen will appear eventually in the runoff or percolate.

### E. 1. c. Phosphorus Mass Balance

Phosphorus is removed from percolating wastewater by fixation and chemical precipitation. For irrigation, the phosphorus loading will usually be well below the capacity of the soil to fix and precipitate the phosphorus. Typically, less than 20 percent of the phosphorus applied is utilized by the crop and the remainder stays in the topsoil [130]. Soil column tests are frequently conducted to determine the fixation capacities of the soil; however, the results of these tests should be used with caution because long-term behavior and the effects of time cannot be duplicated in a short-term test.

For overland flow systems, the removal mechanisms for phosphorus are crop uptake, microbial uptake, and fixation by the soil. Because only a small portion of the effluent applied infiltrates into the soil and crop uptake is small, removal efficiencies are generally low, ranging reportedly from 35 percent at Melbourne, Australia [76], to 50 percent at Ada, Oklahoma [164]. For infiltration-percolation systems, fixation and chemical precipitation in the soil are responsible for phosphorus removal. As with irrigation, the capacity of the soil to remove phosphorus can be estimated from laboratory tests. This capacity can be quite high even for sandy soils with relatively low fixation capacities. Bouwer [21] reports 95 percent removal after 200 feet (61.0 m) of travel at a loading of 21,000 lb/acre/yr (23,450 kg/ha/yr).

### E. 1. d. Organic Loading Rates

The average daily organic loading rate should be calculated from the liquid loading rate and the BOD concentration of the applied effluent. Thomas [163, 165] has estimated that between 10 and 25 lb/acre/day (11.2 and 28.0 kg/ha/day) are needed to maintain a static organic-matter content in the soil. Additions of organic matter at these rates help to maintain the tilth of the soil, replenish the carbon oxidized by microorganisms, and would not be expected to pose problems of soil clogging. Higher loading rates can be managed, depending upon the type of system and the resting period.

Irrigation – Using the range of 10 to 25 lb/acre/day (11.2 to 28.0 kg/ha/day) of BOD as a reference, the addition of 2 lb/acre/day (2.2 kg/ha/day) or less from a typical secondary effluent applied for irrigation will certainly not pose a problem of organic buildup in the soil. When primary effluent is used, organic loading rates may exceed 20 lb/acre/day (22.4 kg/ha/day) without causing problems [125].

Resting periods are standard with most irrigation techniques. These periods give soil bacteria time to break down organic matter and allow the water to drain from the top few inches. Aerobic conditions are thus restored as air penetrates into the soil. Resting periods for spray irrigation may range from less than a day to 14 days, with 5 to 10 days being common [65]. The resting period for surface irrigation can be as long as 6 weeks but is usually between 6 and 14 days [130]. The resting period depends upon the crop, the number of individual plots in the rotation cycle, and management considerations.

Infiltration-Percolation – Organic loading is an important criterion for infiltration systems, because it is related to the development of anaerobic conditions. To meet the oxygen demand created by the decomposing organic and nitrogenous material, an intermittent loading schedule is required. This allows air to penetrate the soil and supplies oxygen to the bacteria that oxidize the organic matter and ammonium.

Bouwer [20] reports BOD loadings of 45 lb/acre/day (50.4 kg/ha/day) using secondary effluent and a liquid loading of 300 ft/yr (91.4 m/yr). The application cycle consisted of loading for 14 days, followed by 10 days of resting in the summer and 20 days of resting in the winter. Additional information on loading rates and resting periods may be found in Wastewater Treatment and Reuse by Land Application [125].

Industrial wastes have been loaded successfully on infiltration-percolation systems at 150 lb/acre/day (168.1 kg/ha/day) of BOD [125]. Thomas [165] reports BOD loadings of 166 lb/acre/day (186.1 kg/ha/day) of septic tank effluent with organic residues in the soil of less than 16 lb/acre/day (17.9 kg/ha/day). He reports that this high loading can be used on sandy soils for extended periods without resulting in the detrimental accumulation of organic residues in the soil, and that during a 10-year period of operation, organic residues in the soil would increase by no more than 3 percent of the weight of the top 6 inches (15.2 cm) of good mineral soil.

Overland Flow – The limits of organic loading for the overland flow method are at present undefined. High-strength organic wastes have been treated at BOD loadings of 40 to 100 lb/acre/day (44.8 to 112 kg/ha/day) [125]. Kirby [76] reports that the grass filtration system at Melbourne, Australia, is loaded at 68 lb/acre/day (76.2 kg/ha/day) of BOD with a 96-percent removal efficiency. Thomas [164] reports 92- to 95-percent removal of BOD at loadings of 14 to 18 lb/acre/day (15.7 to 20.2 kg/ha/day) with higher removals observed at the higher organic and liquid loading rates. Higher organic loading rates can probably be used.

Because the organic matter is filtered out by the grass, litter, and topsoil, and is reduced by biological oxidation, the organic content of the soil is not affected substantially.

However, high organic loadings may limit treatment efficiency as a result of the combination of effects of BOD and liquid loading on the creation of anaerobic conditions. Because overland flow functions in a manner similar to a trickling filter, intermittent dosing has been used successfully with 6 to 8 hours on and 6 to 18 hours off [125]. In Australia, continuous dosing has been used for up to 6 months with the remaining 6 months for resting [76]. Provisions should be made to vary the resting period, depending on climatic conditions, harvesting requirements, and insect control considerations.

E.1.e. Loadings of Other Constituents — Suspended and dissolved solids are the two major types of remaining constituents of interest for land-application systems. Effects of these constituents vary with the type of system.

Large concentrations of suspended solids can clog the components of the distribution system and reduce the infiltration rate into the soil. As a result, preapplication treatment for suspended solids reduction may be necessary (see I-E.5). The organic fraction of the suspended solids when applied to the land is degraded as described previously for BOD. The inorganic or mineral fraction of the suspended solids is filtered out and becomes incorporated into the soil.

Dissolved solids in wastewater may be classified by the extent of their movement through the soil. Chlorides, sulfates, nitrates, and bicarbonates move relatively easily through most soils with the percolating water. These compounds can therefore be leached with applications of wastewater or with rainfall.

Other dissolved solids, such as sodium, potassium, calcium, and magnesium, are exchangeable and react within the soil so that their concentrations in the percolating water will change with depth. Other constituents, such as heavy metals, boron, fluoride, and other trace elements or pesticides, may or may not be removed by the soil matrix, depending upon such factors as clay content, soil pH, and soil chemical balance. On the basis of the analysis of wastewater characteristics (I.B.4) and the BPT requirements for groundwater protection, any constituent suspected of having a limiting loading rate should be identified. The loading rate of that constituent should then be calculated, and the resulting land requirement (as discussed next under I-E.2.a.) should be compared to the areas calculated for liquid or nitrogen loadings.

Irrigation — Different wastewater constituents may be limiting in irrigation design, depending on the objectives, crops, and climate involved. If crop yield or landscape enhancement is the major objective, Water Quality Criteria [176] and Chapman [27] should be consulted to determine the optimum levels of various elements for the particular plant and the possible effects of levels other than optimum on plant quality and yield. Local farm advisers and Agricultural Extension Service agents may be contacted for evaluation of aniticipated special problems.

When maximum effluent application is practiced, the crop selected should be able to tolerate the particular wastewater at the loadings intended. The concentrations of wastewater components will not usually limit the design loadings. provided there is no probability of groundwater contamination by the percolate. If such a danger exists, provisions such as underdrains should be considered.

Infiltration-Percolation — Because of the high liquid loadings involved, the loadings of constituents in even low concentrations can be considerable. Soils used for infiltration-percolation usually have little capacity to retain soluble salts and may retain only portions of the heavy metals and phosphorus. The concentrations of constituents, such as sodium, chloride, or sulfate, allowable in the renovated water may affect the design by requiring special controls on the use of the renovated water.

The TDS and hardness of the percolating water may increase as a result of a lowering of the pH of the water. Reid [132] reports a TDS increase of 11 percent and a hardness increase of 30 percent at the 8-foot (2.4-m) depth at Whittier Narrows, California. It has been suggested that the pH drop from about 7.0 to approximately 6.6 has been caused by nitrification [132]. Bouwer [20] reports only a 4 percent increase in TDS, which he related to evaporation (3 percent) and pH drop (1 percent). A pH drop, whether caused by nitrification or carbon dioxide generated during BOD oxidation, can result in dissolution of calcium carbonate, resulting in an increase in hardness and TDS.

Overland Flow – Because a discharge of effluent that must meet or exceed treatment criteria is usually involved in an overland flow system, the removal of various wastewater constituents is important. The grass and litter in an overland flow system serve to filter out suspended solids but have little effect on dissolved solids. The loadings of most inorganic constituents will not limit the design of overland flow systems, although some increase in TDS may occur if evapotranspiration exceeds precipitation.

## E.2. LAND REQUIREMENTS

The total land area required includes allowances for treatment; buffer zones; storage, if necessary; sites for buildings, roads, and ditches; and land for emergencies or future expansion. If any on-site preapplication treatment, such as screening, sedimentation, biological or chemical treatment, or disinfection, is required, an allowance must be made for the land needed for these facilities. The computation of land requirements is illustrated in Example 2.

E.2.a. Field Area Requirement – The field area is that portion of the land-application site in which the treatment process actually takes place. It is determined by comparing the areas and is calculated on the basis of acceptable loading rates for each different loading parameter (liquid, nitrogen, phosphorus, organic, or others, based on BPT requirements for groundwater protection) and then selecting the largest area. The loading parameter that corresponds to the largest field area requirement would then be the critical loading parameter. The field area requirement based on the liquid loading rate is calculated by:

$$\text{Field Area (acres)} = \frac{1{,}118Q}{L} \qquad (6)$$

where

Q = flowrate, mgd

L = annual liquid loading, ft/yr

or:

$$\text{Field Area (ha)} = \frac{315.6Q}{L} \qquad (7)$$

where

$Q$ = flowrate, l/s

$L$ = annual liquid loading, cm/yr

For loadings of constituents such as nitrogen the field area requirement is calculated by:

$$\text{Field Area (acres)} = \frac{3,040CQ}{L_c} \qquad (8)$$

where

$C$ = concentration of constituent, mg/l

$Q$ = flowrate, mgd

$L_c$ = loading rate of constituent, lb/acre/yr

or:

$$\text{Field Area (ha)} = \frac{31.56CQ}{L_c} \qquad (9)$$

where

$C$ = concentration of constituent, mg/l

$Q$ = flowrate, l/s

$L_c$ = loading rate of constituent, kg/ha/yr

Once the field area has been determined and the critical loading rate has been identified, the resulting new loading rates for the other loading parameters should be computed.

A distinction should be made between field area and wetted area. Field area represents the area of the treatment system. The term wetted area refers to the area to which liquid is directly applied, either the area covered by the diameter of the spray or the area inundated by surface application. The significance of this difference varies with the treatment method.

Irrigation — For spray irrigation, the wetted area may vary from 75 to 100 percent of the field area [131]. The percentage will depend upon the shapes of the fields, the sprinkler discharge patterns, and the degree of spray overlap. The highest ratio of wetted area to field area (0.95-0.99) occurs with flood and ridge and furrow systems.

Infiltration-Percolation — The wetted area should be nearly equal to the field area for most infiltration-percolation systems. For constructed spreading basins, considerable land may be lost in side slopes of the basin levees.

Overland Flow — Terminology for overland flow hydraulic loadings and acreages has not been standardized. Loadings are most often reported in inches per day applied to the total field area. Field area represents the sum of the area under sprays and the runoff area. The wetted area (area under sprays) is significantly less than the field area for current designs using spray application.

Thomas [164] reports a wetted area of 25 percent of the field area, while wetted areas of 40 to 45 percent of field areas have been reported for industrial systems [125]. It should be noted that more than 25 percent of the land in the Paris, Texas, overland flow system does not function as either wetted area or runoff area but is undeveloped [56].

The length of the downhill slope beyond the spray perimeter will vary with the climate, degree of treatment required, and the wastewater characteristics. Thomas [164] reports 88 feet for comminuted domestic wastewater in Ada, Oklahoma, with corresponding BOD removal efficiencies of 92 to 95 percent. Gilde [56] reports that 95 feet (29.0 m) is adequate and 50 feet (15.2 m) is the minimum for cannery wastewater with BOD removal efficiencies greater than 99 percent. A typical range would be one to two spray diameters beyond the spray perimeter.

### E.2.b. Buffer Zone Allowance

Although there is little actual data concerning aerosols, there is considerable concern about the effects of aerosol-borne pathogens. Therefore, application of effluent by spraying may require buffer zones or other measures to ensure that aerosols are contained on the site. Buffer zones ranging from 50 to 200 feet (15.2 to 61.0 m) wide have been reported [125], although requirements for even larger buffer zones may exist. The size of the buffer zone that may be required is dependent on a number of factors, and will generally be controlled by the cognizant public health authority (I-F.2.d).

### E.2.c. Land for Storage

Irrigation and overland flow systems will generally require off-season or winter storage. Storage may also be useful to equalize flowrates or to provide emergency backup. The land required for storage lagoons or ponds may be considerable, especially in the northern states. Even in semiarid Abilene, Texas, 18 percent of the 2,019 acre (817 ha) irrigation farm is used for storage ponds [125].

Infiltration-percolation systems incorporating spreading basins can usually operate throughout the year, if the limiting loading rate was established for winter conditions.

### E.2.e. Land for Future Expansion or Emergencies

Area for potential future expansion of a land-application system should be considered in the planning stage. If it is known that the adjacent land is planned for development and will be unavailable for future use, the system should not be referred to as a long-term solution. Often, it is prudent to obtain excess land for emergency use. Such things as excessive rainfall, breakdown of preapplication treatment operations, or natural disasters would constitute emergencies.

EXAMPLE No. 2 – Calculate the land requirements for a one mgd (43.8 l/s) irrigation system.

Assumptions

1. The design liquid loading rate is 152 in./yr (386 cm/yr) from Example No. 1, or 12.67 ft/yr (3.86 m/yr).
2. On the basis of the nitrogen balance, the nitrogen loading rate is determined to be 650 lb/acre/yr (740 kg/ha/yr). The average total nitrogen concentration in the effluent from preapplication treatment is 18 mg/l.
3. Concentrations of TDS and boron, and the SAR, are within an acceptable range.
4. A buffer zone of 150 feet (45.7 m) is required around the perimeter of the site.
5. A 145 acre-foot (179,000 cu m) storage reservoir (from Example No. 3) of 10 feet (3.05 m) average depth is included on the site. A dike of 50 feet (15.2 m) average width surrounds the reservoir.
6. A total of 4 acres (1.6 ha) is required for buildings, roads, ditches, and other miscellaneous items.
7. Preapplication treatment facilities exist off-site.

Solution

1. The field area required, based on the liquid loading rate is computed from Equation 6:

$$\text{Field area} = \frac{1{,}118 \times 1 \text{ mgd}}{12.67 \text{ ft/yr}} = 88.3 \text{ acres } (35.7 \text{ ha})$$

2. The field area required, based on the nitrogen loading rate, is computed from Equation 8:

$$\text{Field area} = \frac{3{,}040 \times 18 \text{ mg/l} \times 1 \text{ mgd}}{650 \text{ lb/acre/yr}} = 84.2 \text{ acres } (34.0 \text{ ha})$$

A comparison of the two field area requirements shows that the liquid loading rate is controlling; therefore the actual field area required is 88.3 acres (35.7 ha).

3. The area required for storage is:

$$\text{Area of reservoir} = \frac{145 \text{ acre-ft}}{10 \text{ ft}} = 14.5 \text{ acres } (5.9 \text{ ha})$$

Assuming that the reservoir is rectangular with sides of 1,000 and 650 feet (305 and 198 m), the area required for the dike is approximately 4 acres (1.6 ha). The total area required for storage is then 18.5 acres (7.5 ha).

4. The subtotal of the area required is:

| | |
|---|---|
| Total Field Area | 88.3 |
| Storage | 18.5 |
| Buildings, roads, ditches, etc. | 4.0 |
| | 110.8 acres (44.8 ha) |

Assuming that this area is rectangular with sides of 3,000 and 1,600 feet (914 and 488 m), the area required for the buffer zone is approximately 34 acres (13.8 ha). The total area required for the system is then approximately 145 acres (59 ha).

Comments

1. The result of this process is only an approximation of the total land requirements. A more detailed analysis would require that a preliminary layout or site plan be made so that topographic irregularities and irregularities in the shape of the land parcel could be taken into account.

2. In this example, a factor of safety was not applied to the calculation of field area, nor was extra land included for future expansion or emergencies.

## E.3. CROP SELECTION

Proper crop selection is of great importance in the design of irrigation systems, and to a lesser degree, of overland flow systems. It may also be of importance for infiltration-percolation systems in which vegetation is grown on the infiltration surface. Factors that should be considered include: (1) relationship to critical loading parameter, (2) public health regulations, (3) ease of cultivation and harvesting, and (4) the length of the growing season. The four general classes of crops that may be considered are:

- Perennials (forage or fruit crops)
- Annuals (field crops)
- Landscape vegetation
- Forest vegetation

For irrigation systems from which maximum crop yields are desired, the crops considered should be indigenous to the area. Any exceptions to this recommendation should have a sound agronomic basis. For high-rate systems in which water tolerance of the vegetation is necessary, plants that are not indigenous to the area may be grown successfully. In any case, the plants should be compatible with the climate and growing season.

### E.3.a. Relationship to Critical Loading Parameter

Loading rates developed in the previous section should be related to the tolerances and uptake capacities of the intended crops. Compatibility of the loading rates with the potential crop is important to ensure both the survival of the crop and the efficiency of wastewater renovation. In many cases, crop selection will be dependent on a combination of loading parameters, including (1) water requirement and tolerance, (2) nutrient requirements, tolerances, and removal capability, and (3) sensitivity to various inorganic ions.

Water Requirement and Tolerance – Potential crops may be selected on the basis of their suitability to the hydraulic conditions that will exist. The objective is to find a crop able to withstand wetter-than-normal conditions and a soil that is frequently saturated. This may be the case particularly in overland flow and infiltration-percolation systems. The soil characteristics, particularly as related to the infiltration and percolation capacity, will greatly affect the ability of the potential crop to withstand these conditions. Consultation with Agricultural Extension Service representatives, agronomists, or local farmers may be necessary to determine crop tolerances. In cases in which crop selection is based on other criteria, the liquid loading rate may require adjustment on the basis of the water requirement of the chosen crop.

Nutrient Requirements, Tolerances, and Removal Capabilities – Frequently, a crop may be selected because of its removal capacity for essential nutrients, particularly nitrogen and phosphorus. Although nutrient removal through crop uptake and subsequent harvesting is most effective in irrigation systems, it is also of significance in overland flow systems. If required, removal capacities for many specific elements, such as boron, zinc, and copper, may be found in Reed [130] for agricultural crops and Sopper [148, 150] for trees. Typical crop uptake values of nitrogen are shown for a number of selected crops in Table 6.

Potential adverse effects on crops from high concentrations of nutrients should also be considered, particularly when the quality of the crop is of great importance. Excess nitrogen, for example, may cause excessive plant height, late maturation of fruit, and other problems in plants such as grapes [130]. Consultation by the engineer with agronomists or Agricultural Extension Service representatives may be necessary to determine nutrient requirements and tolerances, including seasonal variations.

Sensitivity to Inorganic Ions – Crop selection must often be based on tolerance to the various inorganic ions present in the applied wastewater or to those ions that may build up in the soil after a number of years. Toxic levels of boron and high salinity are the most common problems. The long-term buildup of various heavy metals to toxic levels should be considered. The reduced response in terms of percent yield decrement for various crops in arid and semiarid climates to conductivity levels is shown in Tables 7 and 8. Additional data on tolerances of various crops to certain elements and descriptions of toxic effects may be found in Chapman [27] and references [1, 110, 125, 130, 176]. Suggested tolerance levels for heavy metals for various crops may be found in Melsted [99].

### E.3.b. Public Health Regulations

Various state public health regulations exist with regard to: (1) the types of crops that may be irrigated with wastewater; (2) the degree of preapplication treatment required for certain types of crops; and (3) the methods of application that may be employed. As of 1972, at least 17 states had such regulations [156], which vary widely in several respects. Generally, however, most states prohibit the use of untreated sewage or primary effluent on vegetables grown for human consumption, while some states allow irrigation of vegetables with highly treated, oxidized, and disinfected effluent [125]. Contradicting regulations exist for the irrigation of pasturelands, recreational lands, and other areas [160]. State public health officials or other applicable authorities such as the FDA should be consulted for existing regulations and guidelines. The literature review of public health effects by Sepp [143] may be helpful to the engineer, particularly in states in which regulations are incomplete or do not exist.

### E.3.c. Ease of Cultivation and Harvesting

The ease of cultivation and harvesting of the selected crop may be of importance, particularly for systems in which operation is to remain as simple as possible.

### Table 7. YIELD DECREMENT TO BE EXPECTED FOR FIELD CROPS DUE TO SALINITY OF IRRIGATION WATER WHEN COMMON SURFACE METHODS ARE USED[a]

|  | 0% |  |  | 10% |  |  | 25% |  |  | 50% |  |  | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crop | ECe[b] | ECw[b] | TDS[b] | ECe | ECw | TDS | ECe | ECw | TDS | ECe | ECw | TDS | ECdw[c] |
| Barley | 8 | 5.3 | 3,392 | 12 | 8 | 5,120 | 16 | 10.7 | 6,848 | 18 | 12 | 7,680 | 44 |
| Sugarbeets | 6.7[d] | 4.5 | 2,880 | 10[d] | 6.7 | 4,288 | 13 | 8.7 | 5,568 | 16 | 10.7 | 6,848 | 42 |
| Cotton | 6.7 | 4.5 | 2,880 | 10 | 6.7 | 4,288 | 12 | 8 | 5,120 | 16 | 10.7 | 6,848 | 48 |
| Safflower | 5.3 | 3.5 | 2,240 | 8 | 5.3 | 3,392 | 11 | 7.3 | 4,672 | 14 | 8 | 5,120 | 28 |
| Wheat | 4.7[d] | 3.1 | 1,984 | 7[d] | 4.7 | 3,008 | 10 | 6.7 | 4,288 | 14 | 9.3 | 5,952 | 40 |
| Sorghum | 4 | 2.7 | 1,728 | 6 | 4 | 2,560 | 9 | 6 | 3,840 | 12 | 8 | 5,120 | 36 |
| Soybean | 3.7 | 2.5 | 1,600 | 5.5 | 3.7 | 2,368 | 7 | 4.7 | 3,008 | 9 | 6 | 3,840 | 26 |
| Sesbania | 2.7 | 1.8 | 1,152 | 4 | 2.7 | 1,728 | 5.5 | 3.7 | 2,368 | 9 | 6 | 3,840 | 26 |
| Rice (paddy) | 3.3 | 2.2 | 1,408 | 5 | 3.3 | 2,112 | 6 | 4 | 2,560 | 8 | 5.3 | 3,392 | 24 |
| Corn | 3.3 | 2.2 | 1,408 | 5 | 3.3 | 2,112 | 6 | 4 | 2,560 | 7 | 4.7 | 3,008 | 10 |
| Broadbean | 2.3 | 1.5 | 960 | 3.5 | 2.3 | 1,472 | 4.5 | 3 | 1,920 | 6.5 | 4.3 | 2,752 | 10 |
| Flax | 2 | 1.3 | 832 | 3 | 2 | 1,280 | 4.5 | 3 | 1,920 | 6.5 | 4.3 | 2,752 | 10 |
| Beans (field) | 1 | .7 | 448 | 1.5 | 1 | 640 | 2 | 1.3 | 832 | 3.5 | 2.3 | 1,472 | 12 |

a. From Reference [7].

b. ECe means electrical conductivity of saturation extract in millimhos per centimeter (mmho/cm); ECw means electrical conductivity of irrigation water (in mmho/cm). TDS in mg/L = ECw x 640.

c. ECdw shows maximum concentration of salts in drainage water permissible for growth. Use to calculate leaching requirement (LR = ECw/ECdw x 100 = %) to maintain needed ECe in active root area; Leaching Requirement (LR) means that fraction of the irrigation water that must be leached through the active root zone to control soil salinity at a specified level.

NOTE: Conversion from ECe to ECw assumes a three-fold concentration of salinity in soil solution (ECsw) in the more active part of the root zone due to evapotranspiration. ECw x 3 = ECsw; ECsw ÷ 2 = ECe.

d. Tolerance during germination (beets) or early seedling stage (wheat, barley) is limited to ECe about 4 mmho/cm.

Because the soil may often be saturated, the operation of farm machinery may be difficult or may cause excessive soil compaction, necessitating the selection of a crop requiring little field maintenance. Selection of a perennial crop over an annual crop to avoid annual field preparation and planting may be worth examining.

## E.3.d. Length of Growing Season

The length of the growing season should be considered for potential crops, along with seasonal variations in water requirements, and nutrient uptake. Storage

**Table 8. YIELD DECREMENT TO BE EXPECTED FOR FORAGE CROPS DUE TO SALINITY OF IRRIGATION WATER[a]**

| Crop | 0% | | | 10% | | | 25% | | | 50% | | | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ECe[b] | ECw | TDS | ECe | ECw | TDS | ECe | ECw | TDS | ECe | ECw | TDS | ECdw |
| Bermuda Grass | 8.7 | 5.8 | 3,712 | 13 | 8.7 | 5,568 | 16 | 10.7 | 6,848 | 18 | 12 | 7,680 | 44 |
| Tall Wheat Grass | 7.3 | 4.9 | 3,136 | 11 | 7.3 | 4,672 | 15 | 10 | 6,400 | 18 | 12 | 7,680 | 44 |
| Crested Wh. Grass | 4 | 2.7 | 1,728 | 6 | 4 | 2,560 | 11 | 7.3 | 4,672 | 18 | 12 | 7,680 | 44 |
| Tall Fescue | 4.7 | 3.1 | 1,984 | 7 | 4.7 | 3,008 | 10.5 | 7 | 4,480 | 14.5 | 9.7 | 6,208 | 40 |
| Barley (hay) | 5.3 | 3.5 | 2,240 | 8 | 5.3 | 3,392 | 11 | 7.3 | 4,672 | 13.5 | 9 | 5,760 | 28 |
| Perennial Rye | 5.3 | 3.5 | 2,240 | 8 | 5.3 | 3,392 | 10 | 6.7 | 4,288 | 13 | 8.7 | 5,568 | 26 |
| Harding Grass | 5.3 | 3.5 | 2,240 | 8 | 5.3 | 3,392 | 10 | 6.7 | 4,288 | 13 | 8.7 | 5,568 | 26 |
| Birdsfoot Trefoil | 4 | 2.7 | 1,728 | 6 | 4 | 2,560 | 8 | 5.3 | 3,392 | 10 | 6.7 | 4,288 | 20 |
| Beardless Wild Rye | 2.7 | 1.8 | 1,152 | 4 | 2.7 | 1,728 | 7 | 4.7 | 3,008 | 11 | 7.3 | 4,672 | 22 |
| Alfalfa | 2 | 1.3 | 832 | 3 | 2 | 1,280 | 5 | 3.3 | 2,112 | 8 | 5.3 | 3,392 | 16 |
| Orchard Grass | 1.7 | 1.1 | 704 | 2.5 | 1.7 | 1,088 | 4.5 | 3 | 1,920 | 8 | 5.3 | 3,392 | 18 |
| Meadow Foxtail | 1.2 | .8 | 512 | 2 | 1.3 | 832 | 3.5 | 2.3 | 1,472 | 6.5 | 4.3 | 2,752 | 14 |
| Clover | 1.2 | .8 | 512 | 2 | 1.3 | 832 | 2.5 | 1.7 | 1,088 | 4 | 2.7 | 1,728 | 14 |

a. From Bernstein [7].

b. For explanation of abbreviations, see Table 7.

requirements and renovation efficiency at certain times of the year will be affected by the choice. The advantages of perennials, which have fully developed root systems at the beginning of the growing season, should be compared to the advantages of annual crops that may have higher yields or economic return. Cultivation of more than one annual crop per year may be possible.

## E.3.e. Landscape Requirements

The irrigation of landscape vegetation is a special case in which the vegetation may already exist, or the choice may be limited to a few species of a particular type. The most common type of vegetation is grass, especially for parks and golf courses, where the condition of the turf is usually more important than the renovation of wastewater. In cases in which landscape vegetation is among the crop options, the reduction in the use of potable water and aesthetic and recreational advantages should be balanced against the potential increased preapplication treatment requirements and loading rate restrictions.

## E.3.f. Forestland

Forests offer another crop option that requires special consideration. Most commonly, existing forestlands can be used; however, new forest areas may be established, with species selected on the basis of their suitability to land application. General information on the use of forestlands for land application is contained in Cunningham [31] and Kazlowski [74]. Information on nutrient uptake, growth responses, and general suitability is available for a limited number of tree species in references [1, 130, 148].

## E.4. STORAGE REQUIREMENTS

In almost all land-application systems, storage facilities will be required. Required capacities may range from less than one day's storage to 6 months'. The primary considerations in determining storage capacity are the local climate and the design period of operation; however, storage for system backup and flow equalization should also be considered. The possibility of a secondary use of the stored wastewater should be investigated.

### E.4.a. Length of Operating Season and Climate

Most often, the storage requirements will be based on the period of operation and the climate. Three different conditions can be encountered that necessitate storage:

- Winter weather requiring cessation of operation
- Precipitation requiring the temporary reduction or cessation of application
- Winter weather requiring reduction of winter application rates

Generally, the most convenient method of determining the storage requirement is by means of an extension of the monthly water balance (I.E.1.a.). This method is illustrated in Example 3 for a hypothetical system in which a portion of the flow must be stored during the winter months when application rates are reduced.

When cessation of operation resulting from winter weather is expected, storage requirements should be based on the maximum expected period of nonoperation. The maximum period should be based on a frequency analysis of historical winter weather data. Frost dates, periods of frozen ground conditions, and snow cover should also be considered.

Temporary storage of wastewater may often be necessary when large amounts of precipitation prohibit normal application rates, because of the danger of unwanted runoff, or the effects of hydraulic overloading on crops and renovation efficiencies. The system should be evaluated to determine if excessive precipitation can be retained on the fields or if application should be ceased. Precipitation data should then be analyzed to determine the frequency of conditions requiring temporary reduction or cessation of wastewater application and subsequent storage requirements.

In cases where reduced application rates are necessary for the winter season, an economic trade-off can be made between partial storage in winter versus acquiring more land for winter application. For infiltration-percolation systems, cold weather may require only a reduction in the application rate (I-E.2.c.).

In calculations of storage requirements, it may often be necessary to assume a greater amount of precipitation than was assumed for the liquid loading evaluation (I-E.1.). The amount of precipitation that must be assumed will depend to a large extent on the degree of reliability required for the particular system and the potential effects of reaching or exceeding the storage capacity in any given year. In some cases, it may be prudent to apply a factor-of-safety to the storage capacity (I-E.9.e.).

EXAMPLE No. 3 – Calculate the storage capacity requirements for a one mgd (43.8 l/s) irrigation system.

Assumptions

1. The design precipitation is the wettest year in 50, with average monthly distribution.
2. The total monthly water losses, including evapotranspiration and design percolation are the same as in Example No. 1.
3. The actual field area is 88.3 acres (35.7 ha) (from Example No. 2).
4. The design year begins in October, at which time the storage reservoir is empty.
5. The flow of 1 mgd (43.8 l/s) is constant throughout the year.

Solution – The calculation of storage requirements per acre of field area is shown in Table 9.

1. The effluent available per month is:

$$\text{Eff. available} = \frac{1 \text{ mgd} \times 30.4 \text{ day/mo} \times 36.8 \text{ acre-in./mg}}{88.3 \text{ acre}}$$

$$= 12.7 \text{ in./mo } (32.3 \text{ cm/mo})$$

which is entered into Column 2 of Table 9.

2. From a curve similar to Figure 2, the design annual precipitation for the wettest year in 50 is found to be 17.0 in. (43.2 cm). The precipitation is distributed over the year on the basis of average distribution and entered into Column 3.

Table 9. CALCULATION OF STORAGE VOLUME REQUIREMENTS PER ACRE OF FIELD AREA FOR EXAMPLE NO. 3

| Month (1) | Effluent available, in. (2) | Precipitation, in. (3) | Total, in. (2) + (3) = (4) | Water losses, in. (5) | ΔStorage, in. (4) − (5) = (6) | Total storage, in. (7) |
|---|---|---|---|---|---|---|
| Oct | 12.7 | 0.8 | 13.5 | 13.9 | -0.4 | 0 |
| Nov | 12.7 | 1.3 | 14.0 | 11.5 | 2.5 | 2.5 |
| Dec | 12.7 | 2.9 | 15.6 | 10.8 | 4.8 | 7.3 |
| Jan | 12.7 | 3.0 | 15.7 | 10.7 | 5.0 | 12.3 |
| Feb | 12.7 | 3.0 | 15.7 | 11.5 | 4.2 | 16.5 |
| Mar | 12.7 | 2.7 | 15.4 | 13.1 | 2.3 | 18.8 |
| Apr | 12.7 | 2.1 | 14.8 | 13.9 | 0.9 | 19.7 |
| May | 12.7 | 0.5 | 13.2 | 15.2 | -2.0 | 17.7 |
| Jun | 12.7 | 0.3 | 13.0 | 16.5 | -3.5 | 14.2 |
| Jul | 12.7 | 0.1 | 12.8 | 17.0 | -4.2 | 10.0 |
| Aug | 12.7 | Trace | 12.7 | 16.5 | -3.8 | 6.2 |
| Sep | 12.7 | 0.3 | 13.0 | 14.4 | -1.4 | 4.8 |
| Oct | 12.7 | 0.8 | 13.5 | 13.9 | -0.4 | 4.4 |

Note: 1 inch = 2.54 cm.

3. The total monthly water losses are taken from Column 4 of Table 5 and entered into Column 5 of Table 9.

4. The monthly change in storage volume (Column 6 of Table 9) is computed by subtracting Column 5 from Column 4.

5. The total accumulated storage (Column 7) is computed by summing the monthly change in storage.

6. The maximum storage requirement is found to be 19.7 in. (50.0 cm) occurring in the month of April. This is converted to total storage volume by:

$$\text{Storage vol} = \frac{19.7 \text{ in.} \times 88.3 \text{ acre}}{12 \text{ in./ft}} = 145 \text{ acre ft } (179{,}000 \text{ cu m})$$

## Comments

1. In this example, it was assumed that the reservoir was empty at the beginning of the winter season. In actual practice, this may often not be the case. Consequently, it may be wise to assume an initial amount of storage, or to assume back-to-back wetter-than-normal years if storage volume is critical.

2. In some cases, it may be possible to ensure that the stored water is completely withdrawn during the summer season for the storage design year. This may be possible if design application rates are chosen conservatively or if extra land is included for emergencies.

3. For example purposes, the calculation of storage requirements was conducted separately from the calculation of the water balance (Example No. 1). It may often be convenient to combine these calculations.

4. In this example, a factor of safety was not applied to the total storage volume.

### E.4.b. For System Backup

Storage requirements may be necessary for system backup or to preclude bypassing of wastewater during periods of mechanical failure, maintenance, power failure, or other problems. Storage for this purpose will add to the reliability and flexibility of the system. For systems in which storage requirements are otherwise small, requirements for system backup may be of significance. Consideration should be given to provision for gravity flow to storage backup facilities under conditions of power failure. For additional considerations, the technical bulletin on reliability [35] should be consulted.

### E.4.c. For Flow Equalization

Storage of wastewater for flow equalization may be necessary if daily fluctuations in flow are significant and hinder the proper application of wastewater. The sustained peak flow (I-B.1.) should be analyzed to determine the required storage. Consideration of storage requirements for this purpose is normally necessary only for systems for which no other storage requirements exist. In most other cases, daily fluctuations in flow are easily absorbed in the larger storage capacities required for other purposes.

### E.4.d. Secondary Uses of Stored Wastewater

After storage requirements have been determined, the possibility of secondary use of the stored wastewater (prior to land application) should be investigated. The areas of potential use are highly dependent on the quality of the stored wastewater and the degree of preapplication treatment it has received. Perhaps the most noteworthy of the potential uses is as industrial cooling water.

## E.5. PREAPPLICATION TREATMENT REQUIREMENTS

The degree of treatment required prior to land application will depend upon a number of factors, including: (1) public health regulations, (2) the loading rate with respect to critical wastewater characteristics, and (3) the desired effectiveness and dependability of the physical equipment. It is conceivable for a system in which long-term winter storage is required that the degree of treatment determined from the preceding considerations will not be adequate to prevent odors from developing in the storage ponds. In such cases, costs for increased treatment may be weighed against designing the storage ponds as stabilization ponds to prevent odor generation.

Existing treatment facilities should also be evaluated, and other design criteria – particularly loading rates and crop selection – should be reconsidered in light of the preapplication treatment requirements.

### E.5.a. Public Health Considerations

Public health considerations, and regulations (in states where they exist), are normally the most important factors in determining the required degree of preapplication treatment. Factors that should be considered include:

- Type of crop grown
- Intended use of the crop
- Degree of contact of the public with the effluent
- Intended secondary use of the application area
- Method of application

State regulations for treatment prior to irrigation differ considerably. For example, the irrigation of certain crops to be eaten raw by humans may require either secondary treatment with disinfection or advanced wastewater treatment with disinfection, or it may be prohibited altogether [156]. State public health officials should be consulted for existing regulations and guidelines. As an illustrative example, the regulations for California are included in Appendix E. In addition, it may also be helpful to contact the FDA or other appropriate agencies, particularly when state guidance is lacking or not complete.

### E.5.b. Relationship to Loading Rate

The degree of preapplication treatment given the wastewater prior to application will often have a considerable effect on the loading rate, and the final quality of the renovated water. Of concern are those wastewater constituents that may tend to limit the application rate, or for which the degree of renovation by land application is insufficient. Concentrations of suspended solids must often be reduced to prevent soil clogging and land surface coating at design liquid loading rates. Concentrations of other constituents – such as BOD, nitrogen, phosphorus, and various inorganic ions – may need to be reduced to prevent the effects of overloading and to ensure the required quality of the renovated water. In many cases, liquid loading rates may be increased with no adverse effects on the renovated water quality, if the concentrations of various constituents are reduced.

### E.5.c. Relationship to Effectiveness of Physical Equipment

The effectiveness and dependability of the pumping and distribution system will be largely affected by the degree of preapplication treatment, especially with respect to reduction of suspended solids. High concentrations of grit and suspended solids may cause: (1) the clogging of sprinkler nozzles, (2) the scoring of pump parts, and (3) sedimentation in pipes and conduits. High-pressure spray irrigation systems are normally the most susceptible to damage. Grease and oil can also cause maintenance problems in valves, pipelines, and sprinklers.

## E.6. MANAGEMENT CONSIDERATIONS

Management considerations should be kept in mind throughout the planning stage of the project. Factors that should be considered include: (1) system control and maintenance, (2) manpower requirements for operation and maintenance, (3) monitoring requirements, and (4) emergency procedures and safeguards. Detailed procedures should be incorporated into the Operation and Maintenance Manual, which is discussed in Part III.

### E.6.a. System Control and Maintenance

The method and degree of system control and maintenance requirements should be evaluated for each of the prospective land-application alternatives. System control may be manual or partially automatic, depending on the complexity of the system and the degree of variation expected in operating conditions. Most systems will require direct control; however, for irrigation systems in which effluent is supplied to independent farmers, control in possible only through contract agreements. Maintenance requirements should be realistically assessed, with emphasis on dependability of the system.

### E.6.b. Manpower Requirements

Manpower requirements are related directly to the methods of system control and the maintenance requirements. The approximate number of personnel required should be determined, along with some indication of the necessary personnel qualifications and training requirements. Tchobanoglous [162], as shown in Table 10, has estimated annual manhour requirements for hypothetical 1-mgd

(43.8 l/s) land treatment systems. Staffing requirements are also discussed in references [49, 120].

Table 10. ESTIMATED ANNUAL MANHOUR REQUIREMENTS FOR LAND-APPLICATION ALTERNATIVES WITH A DESIGN FLOW OF 1.0 MGD[a] [162][b]

| | Annual manhours | | |
|---|---|---|---|
| Category | Irrigation | Overland flow | Infiltration-percolation |
| Supervisory[c] | 416 | 416 | 416 |
| Clerical | 104 | 104 | 104 |
| Laboratory | 416 | 416 | 416 |
| Yard | 208 | 208 | 208 |
| Operation | 1,040 | 832 | 520 |
| Maintenance | 1,248 | 1,040 | 416 |
| Total | 3,432 | 3,016 | 2,080 |

a. 1 mgd = 43.8 l/s

b. Labor requirements for preapplication treatment are not included.

c. Includes preparation of reports.

## E.6.c. Monitoring Requirements

The system must be evaluated to determine monitoring requirements necessary to ensure that proper renovation of wastewater is occurring and that environmental degradation is not. In many states, monthly self-monitoring reports must be submitted to the agency responsible for water pollution control. In addition, monitoring may also be conducted for design refinement or research purposes. Generally, water-quality monitoring is important for each stage of the treatment process, including the groundwater and any renovated water that is recovered for reuse or discharge.

For many land-application systems, particularly those with significant deep percolation rates, the monitoring requirement of primary importance in the planning stage will be that of groundwater. A network of monitoring wells, or other monitoring devices, both on and off the site will often be necessary and will require significant planning. Special agreements may need to be formulated to drill and maintain access to off-site wells. Hydrogeologic considerations pertaining to groundwater flow and the proper placement of monitoring wells are discussed by Parizek [117].

### E.6.d. Emergency Procedures

Emergency operating procedures should be considered at this point if serious environmental damage could result from equipment breakdown, severe weather, or power loss. An analysis should be made of the detrimental results that would occur if power service were interrupted for various lengths of time.

## E.7. COST-EFFECTIVENESS ANALYSIS

To properly select the best wastewater treatment alternative, a cost-effectiveness analysis must be performed. To conduct such an analysis, detailed cost estimates must be prepared. The cost estimates for each alternative must be compared on an equivalent basis in terms of total present worth or annual cost. For example, the total annual cost of an alternative would include costs for operation, maintenance, and supervision and the amortized capital cost.

Federal regulations on Cost-Effectiveness Analysis (40 CFR 35) should be consulted, along with applicable state regulations for the proper methods of conducting the analysis. Capital and operating cost considerations of importance for land-application systems are discussed in the following subsections, while social and environmental costs are discussed in the following section on Environmental Assessment.

### E.7.a. Capital Cost Considerations

Capital costs of importance for land-application systems include: acquisition of land, easements, water rights procurement and rights-of-way; relocation of buildings and residents; materials and construction costs for preapplication treatment facilities, earthwork, transmission, distribution, collection (for overland flow and underdrained systems), and monitoring facilities; administrative, legal, and engineering fees startup costs; and interest during construction. Special considerations for capital cost estimations for land-application systems — including construction cost indexes, service life of equipment, and land costs — are discussed in the following subsections.

E.7.a.1. Construction or Other Cost Index — Because costs are changing and vary geographically, cost indexes published periodically are most useful in determining current local costs. An estimate of the cost of construction of an item can be made at one date and referenced to a cost index. To determine the comparable present cost, the current index is located and the cost is updated by multiplying by the ratio of the two indexes.

A common index in the construction industry is the Engineering News Record Construction Cost (ENRCC) index, which is weighted toward building and heavy construction. For conventional treatment plants, a more appropriate index is the EPA Sewage Treatment Plant index. For pipelines and drainage systems, the EPA Sewer Construction Cost index can be used. All three indexes are published in Engineering News Record.

E.7.a.2. Service Life of Equipment — The service life of much of the equipment used in land-application systems is highly variable. Standard service lives for conventional treatment processes are presented in the Federal Regulations on Cost-Effectiveness Analysis (40 CFR 35). Special service lives contained in Table 11 have been suggested by the Sprinkler Irrigation Association [155], and the University of Missouri Extension Division [1]. It should be noted that these service lives are for standard irrigation equipment used typically for periodic use during 4 to 6 months of the year. If irrigation machines are specially designed for wastewater operations, they can be expected to attain similar service lives. Therefore, factors particular to the system under consideration that may affect the expected service life include the annual period of operation, frequency of application, and wastewater characteristics.

E.7.a.3. Land Costs — Costs for land can be a considerable part of the initial capital cost, particularly for irrigation systems and for systems in relatively developed areas. Alternative methods of acquisition, as discussed in the previous section, should be compared on a cost-effective basis when praticable. Costs related to land acquisition, such as the acquisition of easements and rights-of-way and the relocation of residents, should also be included. In the cost-effectiveness analysis, land shall have a salvage value at the end of the planning period equal to its prevailing market value at the time of the analysis.

### E.7.b. Fixed Annual Costs

Annual costs for operation and maintenance should be included in the cost analysis through the planning period (20 years). Fixed annual costs include labor, maintenance, supplies, and monitoring. Inflation of wages and prices should not be included unless significant changes in the relative prices of certain items are anticipated (40 CFR 35).

### E.7.c. Flow-Related Annual Costs

Power is the major annual cost that depends on the annual quantity of wastewater treated. Economic returns, such as those from the sale of crops and/or renovated water, should also be considered. Costs of disposal should be included if the crop or vegetation is not marketable.

### E.7.d. Nonmonetary Factors

Social and environmental factors and economic impacts are discussed in Section F.

## Table 11. SUGGESTED SERVICE LIFE FOR COMPONENTS OF AN IRRIGATION SYSTEM [155] and [1]

| Component | Service life | | |
|---|---|---|---|
| | Hours[a] | or | Years |
| Well and casing | | | 20 |
| Pump plant housing | | | 20 |
| Pump, turbine: | | | |
| Bowl (about 50% of cost of pump unit) | 16,000 | or | 8 |
| Column, etc. | 32,000 | or | 16 |
| Pump, centrifugal | 32,000 | or | 16 |
| Power transmission: | | | |
| Gear head | 30,000 | or | 15 |
| V-belt | 6,000 | or | 3 |
| Flat belt, rubber and fabric | 10,000 | or | 5 |
| Flat belt, leather | 20,000 | or | 10 |
| Power units: | | | |
| Electric motor | 50,000 | or | 25 |
| Diesel engine | 28,000 | or | 14 |
| Gasoline or distillate: | | | |
| Air-cooled | 8,000 | or | 4 |
| Water-cooled | 18,000 | or | 9 |
| Propane engine | 28,000 | or | 14 |
| Open farm ditches (permanent) | | | 20 |
| Concrete structures | | | 20 |
| Concrete pipe systems | | | 20 |
| Wood flumes | | | 8 |
| Pipe, surface, gated | | | 10 |
| Pipe, water works class | | | 40 |
| Pipe, steel, coated, underground | | | 20 |
| Pipe, aluminum, sprinkler use | | | 15 |
| Pipe, steel, coated, surface use only | | | 10 |
| Pipe, steel galvanized, surface only | | | 15 |
| Pipe, wood buried | | | 20 |
| Sprinkler heads | | | 8 |
| Solid set sprinkler system | | | 20 |
| Center pivot sprinkler system | | | 10-14 |
| Side roll traveling system | | | 15-20 |
| Traveling gun sprinkler system | | | 10 |
| Traveling gun hose system | | | 4 |
| Land grading[b] | | | None |
| Reservoirs[c] | | | None |

[a] These hours may be used for year-round operations. The comparable period in years was based upon a seasonal use of 2,000 hr per year.

[b] Some sources depreciate land leveling in 7-15 years. However, if proper annual maintenance is practiced: figure only interest on the leveling costs. Use interest on capital invested in water right purchase.

[c] Except where silting from watershed above will fill reservoir in an estimated period of years.

## E.8. FLEXIBILITY OF ALTERNATIVE

Items that allow flexibility should be included in each element of the design. Flexibility in the design of the system should generally be considered with respect to: (1) changes in treatment requirements, (2) changes in wastewater characteristics, (3) ease of expansion, (4) changes in land utilization, and (5) technological advances.

### E.8.a. Changes in Treatment Requirements

The alternative plan should include provisions to upgrade water quality to meet more stringent treatment requirements. Various methods of upgrading could include increased preapplication treatment and reduction of application rates.

### E.8.b. Changes in Wastewater Characteristics

In some cases, changes in wastewater characteristics may result from changes in the water supply, new industries, or changes in the effluent characteristics of existing industries. An assessment should be made of the ability of the system to handle these potential changes, particularly increases in certain critical wastewater constituents. Compensating modifications to the system, such as increased preapplication treatment or reduced loading rates, should be identified.

### E.8.c. Ease of Expansion

Careful consideration should be given to the design capacity of the land-application system and to the ease with which the system can be expanded. Both planned stages of expansion and the need for expansion that might result from unforeseen circumstances should be considered. All components of the system that will be affected by expansion should be considered including:

- Amount of land available
- Storage capacity
- Preapplication treatment capacity
- Transmission facilities

The environmental impact of potential expansions should also be evaluated.

### E.8.d. Changing Land Use

Future modifications to a land treatment system may be necessary because of changes in adjacent land use. For example, a treatment system originally situated in an agricultural or undeveloped area may, after a number of years, become surrounded by residential, commercial, or industrial developments. Requirements for odor control and aesthetics may become more strict and unforeseen health concerns may arise. Modifications to the system, such as additional buffer zones and stricter control procedures, may be necessary. Treatment alternatives should be evaluated for effects that vary with different uses of the surrounding land.

### E.8.e. Technological Advances

Future system modifications resulting from technological advances may be possible. Wastewater treatment by land application is presently the subject of a great deal of study and research. As a result, many new guidelines and new techniques are anticipated. Advances may be possible in preapplication treatment, application techniques, system monitoring, and in the knowledge of soil-water-plant relationships.

## E.9. RELIABILITY

The reliability and dependability of the system are critical, particularly if the adverse effects of an operational breakdown or a poorly operating system may be great. Areas of susceptibility, such as nozzle clogging, lack of standby equipment, or lack of storage, should be identified and sufficient safeguards employed whenever possible. A number of reliability features, including factors-of-safety, backup systems, and contingency provisions, should be included in the design of land-application systems (II-C.9.). In most cases, the requirement for these features should also be addressed in the preliminary plan. For additional considerations, the EPA technical bulletin on reliability [35] should be consulted.

### E.9.a. To Meet or Exceed Discharge Requirements

The reliability of the system should be assessed with respect to its ability to meet or exceed present and future discharge requirements consistently. This reliability should be assessed under both normal operating and potential abnormal conditions.

### E.9.b. Failure Rate Due to Operational Breakdown

The possibility of system failure resulting from operational breakdown of various components should be evaluated. The breakdown of the physical equipment and preapplication treatment facilities and the temporary inability of the soil to accept further application represent system failures. The consequences of system failure should be evaluated and additional safeguards, including the use of backup systems, should be considered.

### E.9.c. Vulnerability to Natural Disasters

The vulnerability of the system to natural disasters, such as earthquakes, hurricanes, tornadoes, and floods, should be assessed. The probable consequences should be considered, and safeguards, when they are feasible, should be employed. Possible courses of action to deal with such events should be included in the operation and maintenance manual.

### E.9.d. Adequate Supply of Required Resources

The reliability of the system should be evaluated with respect to the adequacy of both the present and the anticipated future supply of required resources. Resources that may require evaluation include: power, material for soil additions, manpower, and chemicals required for preapplication treatment.

### E.9.e. Factors-of-Safety

One of the more significant reliability features that should be addressed in the preliminary planning stage is the inclusion of factors-of-safety in the design of various system components, such as flow capacities, field area requirements, and storage capacities. It is usually prudent to view the entire system when evaluating the need for factors-of-safety, because the reliability of one particular component often affects the degree of reliability necessary for other components.

# Section F

# ENVIRONMENTAL ASSESSMENT

The impact of the project on the environment, including public health, social, and economic aspects must be assessed for each land-application alternative. Environmental assessments are required for all federally funded projects, and similar reports are required by many state and local governments. This section is not intended to replace existing guidelines (40 CFR 6) for the preparation of environmental assessments, but instead is designed to highlight some of the important considerations particular to land application.

In accordance with existing guidelines, environmental assessment will generally consist of:

- Description of the environmental setting
- Determination of components affected
- Evaluation of possible methods of mitigation of adverse effects
- Determination of unavoidable adverse effects
- Evaluation of overall and long-term effects

Environmental component interactions should be considered and measurable parameters identified if possible.

## F.1. ENVIRONMENTAL IMPACT

Environmental components that may be affected by land-application systems include: (1) soil and vegetation, (2) groundwater, (3) surface water, (4) animal and insect life, (5) air quality, and (6) local climate. Effects on the soil, vegetation, and groundwater are normally the most critical, with the effects on surface water being critical at times.

### F.1.a. Soil and Vegetation

The effects of land application on the soil and vegetation can be either beneficial or adverse, with the overall effect most often being mixed. Effects on surrounding land and vegetation may be brought about by changes in various conditions, such as groundwater levels, drainage areas, and microclimates.

Soil conditions, including drainage characteristics and levels of chemical constituents, may be affected by land application. Infiltration and percolation capacities may decrease as a result of clogging by suspended solids, although proper management techniques including resting periods and soil surface raking may help to mitigate this condition. Rates may also increase or decrease as a result of changing chemical conditions, such as the pH and sodium content of the soil. Long-term effects on the soil chemistry, such as the buildup of certain constituents to toxic levels, may be critical in land-application systems, Effects on soil conditions should be predicted initially, and appropriate monitoring requirements should be defined. Various references, particularly Thomas and Law [167], may be helpful in predicting soil effects.

The effects on vegetation are usually beneficial for a well-operated system. Virtually all essential plant nutrients are found in wastewater and should stimulate plant growth. Toxic levels of certain constituents in the soil, which may reduce growth or render crops unsuitable for the intended use must be evaluated [27]. Excess hydraulic loadings or poor soil aeration may also be harmful to plant growth.

### F.1.b. Groundwater

The groundwater quality and level will be affected by most land-application systems. Exceptions would be many overland flow, underdrained, and pumped withdrawal systems. Wastewater constituents that are not used by the plants, degraded by microorganisms, or fixed in the soil may leach to the groundwater. Nitrate nitrogen is the constituent of most concern; however, heavy metals, phosphorus, organics, total dissolved solids, and other elements discussed in I-B.4 may also be of significance.

Groundwater levels may be affected by land application, particulary for infiltration-percolation systems. In turn, groundwater flow may be affected with respect to both rate and direction of movement. The direction and effects of the altered groundwater flow must be predicted, and appropriate monitoring requirements defined.

### F.1.c. Surface Water

Surface waters may be affected directly by (1) discharge from an overland flow, underdrained, or pumped withdrawal system, (2) interception of seepage from an infiltration-percolation system, or (3) undesired surface runoff from the site. Both surface water quality and rate of flow may be influenced. Changes in water quality will be regulated by federal, state, or regional standards. Effects on surface water flow should be investigated both with respect to possible increased and decreased rates of flow. Wastewater reuse systems, used to replace systems previously discharging to a surface water, will result in decreased flows with possible adverse consequences to previous downstream users, or existing fisheries.

### F.1.d. Animal and Insect Life

Treatment by land application may result in changes in conditions, either favorably or adversely affecting certain indigenous terrestrial or aquatic species. Beneficial effects, such as the increased nutritive value of animal forage, should be compared to possible adverse effects, such as the disruption of natural habitat, for each species of concern. Little information exists on this subject, but Sopper [148] reports some initial findings. The possibility of insects or rodents acting as disease vectors is discussed separately under Public Health Effects (I-F.2.b.).

### F.1.e. Air Quality

Air quality may possibly be affected through the formation of aerosols from spray systems and through odors. With aerosols, the primary concern is with transmission of pathogens, which will be discussed further under Public Health Effects. Odors are caused principally by anaerobic conditions at the site or in the applied wastewater. Correction of these conditions is the only permanent cure.

### F.1.f. Climate

Land-application systems, particularly large irrigation or overland flow systems, may have a limited but noticeable effect on the local climate. Air passing over a site will pick up moisture and be cooled, resulting in a localized reduction in temperature. Original conditions are normally regained within a short distance from the site [125].

## F.2. PUBLIC HEALTH EFFECTS

When evaluating the overall environmental impact of an alternative, special consideration should be given to those effects that relate directly to the public health. In many cases, state health regulations and guidelines serve to protect against many of the effects. Public health effects that should be considered include: groundwater quality, insects and rodents, runoff from site, aerosols, and contamination of crops. Overviews of public health effects that may be helpful are contained in references [13, 130, 143, 152].

### F.2.a. Groundwater Quality

The quality of the groundwater will be of major concern when it is to be used as a potable water supply, particularly when an infiltration-percolation system is planned. A sufficient degree of renovation will be required to meet the BPT requirements for groundwater protection. Nitrates are the most common problem, but other constituents, including stable organics, dissolved salts, trace elements, and pathogens should be considered. Extensive monitoring and control practices must be planned.

### F.2.b. Insects and Rodents

Because of the possibility of contamination from pathogens in the wastewater, the control of insects and rodents on a land-application site is more critical than on a conventional irrigation site. Conventional methods of control will normally be required for most pests.

Mosquitoes are a special problem because they will propagate in water standing for only a few days. Elimination of unnecessary standing water and sufficient drying periods between applications are the most effective methods of control.

### F.2.c. Runoff from Site

Applied effluent should not be allowed to run off the site except in systems designed for surface runoff (e.g., overland flow). The extent to which runoff from storm events must be controlled depends upon the water quality objectives of the surface water and the possible effects of such runoff on water quality. Few data are available to assess storm runoff effects from land-application sites.

### F.2.d. Aerosols

Generally, the danger of aerosols lies in their potential for the transmission of pathogens. Aerosols are microscopic droplets that conceivably could be inhaled into the throat and lungs. Aerosol travel and pathogen survival rate are dependent on several factors, including wind, temperature, humidity, vegetative screens, and other factors. Methods of reduction should be employed to ensure that transmission of aerosols is minimized, with probable travel under normal conditions being limited to an acceptable area. This area should be determined on the basis of the proximity of public access. Sorber [152] and Sepp [143] present discussions of this issue and discuss the research on the subject.

Safeguard measures that may be employed against aerosol transmission include:

- Buffer zones around the field area
- Sprinklers that spray laterally or downward with low nozzle pressure

- Rows of trees or shrubs
- Cessation of spraying or spraying only interior plots during high winds
- Combinations of the enumerated measures with adequate disinfection

### F.2.e. Contamination of Crops

The effect of effluent irrigation on crops, with regard to safety for consumption, is a matter of some concern. Many states have regulations dealing with the types of crops that may be irrigated with wastewater, degrees of preapplication treatment required for various crops, and purposes for which the crops may be used. The proposed California regulations are included in Appendix E, and are offered as an example. Individual state health departments should be consulted, since regulations vary widely from state to state. Additional information on the contamination of crops may be found in Sepp [143], Rudolfs [135], and Bernarde [13], or by contacting the FDA or other applicable agencies.

## F.3. SOCIAL IMPACT

The overall effects of the proposed system should be evaluated in light of their impact on the sociological aspects of the community. Included in the evaluation should be considerations of: relocation of residents, effects on greenbelts and open space, effects on recreational activities, effects on community growth, and effects on the quality of life.

### F.3.a. Relocation of Residents

The requirement for large quantities of land, particularly for irrigation and overland flow systems, often necessitates the purchase of land and possibly the relocation of residents. For federally funded projects, the acquisition of land and relocation of residents must be conducted in accordance with the Uniform Relocation Assistance and Land Acquisition Policies Act of 1970. In such cases, the advantages of the proposed treatment system must be weighed against the inconvenience caused affected residents, and then compared with other alternatives.

### F.3.b. Greenbelts and Open Spaces

Proposed treatment systems should be evaluated from an aesthetic point of view and with respect to the creation or destruction of greenbelts and open spaces. Disruption of the local scenic character is often unnecessary and undesirable, while through proper design and planning, the beauty of the landscape can often be enhanced. Reforestation and reclamation of disturbed areas, such as those resulting from strip mining operations, are possible beneficial effects.

### F.3.c. Recreational Activities

The net result of the treatment system on recreational facilities should be considered. Existing open space or parks may be disrupted; however, other recreational areas may be created or upgraded. Irrigation of new parks or golf courses and recreational use of renovated water are possibilities for increasing the overall value of a proposed treatment system.

### F.3.d. Community Growth

The effects of a new treatment system may stimulate or discourage the growth of a community, both in terms of economics and population. Often, improved wastewater treatment service may allow new construction or expansion in the service area. Such growth may consequently tax other existing community services. The potential of the treatment system for affecting community growth should be evaluated, and the subsequent effects on other aspects of the community documented.

## F.4. ECONOMIC IMPACT

An evaluation of the economic impact should include an analysis of all economic factors directly and indirectly affected by the treatment system. Many factors common to conventional systems apply; however, additional factors may be applicable to various land-application systems. Possible additional factors include:

- Change in value of the land used and adjacent lands
- Loss of tax revenues as a result of governmental purchase
- Conservation of resources and energy
- Change in quality of ground or surface waters
- Availability of an inexpensive source of water for irrigation

The effect of the treatment system on the overall local economy should then be appraised, especially with respect to financing and the availability of funds for the long-term operation and maintenance of the system.

## Section G

## IMPLEMENTATION PROGRAM

Selection of the best alternative must be based on an assessment of the cost-effectiveness and the overall impact of the alternatives for wastewater management. To ensure that the best system is selected by the decision makers, all aspects of the alternatives should be made available for public review and evaluation, including the engineer's recommendation. Re-evaluation and modification of the plans may be necessary before a system is selected and general acceptance is received. A long-range wastewater management plan should be included with the implementation schedule.

### G.1. PUBLIC INFORMATION PROGRAM

The establishment of an extensive public information program at the earliest possible time is wise, especially when alternatives under consideration may be controversial. Public involvement to the maximum possible extent should be sought, with feedback to planners and decision makers.

### G.1.a. Approaches to Public Presentation

In many cases, public opposition to proposed land-application systems can be related to lack of knowledge or understanding of the fundamentals involved. Consequently, a well-planned information and education program is highly desirable, and in many cases, required. Effective presentation will usually entail a combination of some or all of the following approaches.

G.1.a.1. Local Officials – Close liasion should be maintained with all local officials who may be directly or indirectly concerned with the project or its effects. The maximum amount of useful information should be passed on to these officials at the earliest possible time to ensure their thorough understanding and continuing support. Properly informed officials may in turn become useful and integral members of the public information program through public addresses and contacts with various citizen and special-interest groups.

G.1.a.2. Public Hearings – Public hearings, which are required for most projects, allow individuals and representatives of groups to speak and present written statements of their viewpoints. These hearings should be conducted in accordance with Public Participation in Water Pollution Programs (40 CFR 105).

Notification of the hearing should be extensive and in addition to advertisements in the mass media should include notification by mail to all groups, agencies, and individuals who may have an interest. To ensure that key decision makers are present, personal telephone invitations may be necessary. The hearing should be recorded and should be followed up by resolution of disagreements, corrections of deficiencies, additional hearings, or any other measures that may be necessary.

G.1.a.3. Mass Media – The mass media, including local newspapers, radio, and television may be helpful in dissemination of general information through articles, special features, and interviews. Additionally, the mass media should be utilized for notification and advertisement of hearings and other public meetings.

G.1.a.4. Local Residents and Landowners – Local residents and landowners, who may be displaced by the project, and those who are to be its neighbors must be kept informed of current planning. Special information programs, through letters, special meetings, and other means, are often necessary to minimize opposition and to preclude possible legal conflicts that may result from unwarranted assumptions and fears.

G.1.a.5. Special-Interest Groups – A wide variety of special-interest groups – including sportsmen's clubs, conservation groups, and taxpayer organizations – may be concerned with the project and its effects. Areas of concern will be widely varied, but every effort should be made to anticipate them and to address them at the earliest possible stage. Many well-informed special-interest groups can be expected to add their support to the intended project and may be valuable in helping to continue the public information program.

### G.1.b. Public Opinion

Public opinion may be expressed by various means, including: reaction at public hearings, statements of various groups, letters, polls, and elections. Expression of public opinion should be encouraged at an early stage so that adequate consideration and response may be given to areas of concern. Every effort should be made to ensure that all areas of concern are met with reasonable responses based on a review of the project plans. Responses may be either explanations and justifications or modifications to the portions of the plan in question.

## G.2. LEGAL CONSIDERATIONS

Legal conflicts may sometimes be unavoidable in the implementation of land-application systems, particularly in the areas of land acquisition and water rights. To avoid later problems legal counsel may be desirable early in the planning stage to outline legal constraints and ensure the overall legality of the project. Possible areas of conflict should be anticipated and settled as quickly as possible.

## G.3. REEVALUATION OF ABILITY TO IMPLEMENT PROJECT

Prior to the submission of the facilities plan, the entire project should be reviewed and reevaluated. Considerations, such as public opinion, legal conflicts, and method of financing including the possible need for bond elections, should be weighed against alternative concepts. The overall effect of these considerations on the ability to implement the project should be assessed.

## G.4. IMPLEMENTATION SCHEDULE

An implementation schedule is necessary to ensure orderly progress toward completion of the project and to set up a long-range management plan. The long-range plan must be formulated to ensure that the recommended courses of action for wastewater management are carried out in an orderly manner throughout the planning period. It is also imperative that the management plan be designed so that technical and operational changes can be incorporated as necessary during the planning period.

For construction purposes, the schedule should include goals for both beginning and completion dates for various stages of the project. All key dates and project stage sequences should be shown graphically for ease in understanding.

The implementation program should also document the steps in financing of the system costs. Users charges and industrial cost recovery are required for all projects receiving federal funds (40 CFR 35 regulations in the Federal Register, August 21, 1973, and February 11, 1974). Costs that are eligible for grant funding must be identified. Costs to be borne by the community should be indicated on a per capita basis, with repayment and cost-sharing by industries included. These are crucial issues in which the public will be most interested.

# PART II

# DESIGN PLANS AND SPECIFICATIONS

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## Section A

## AGREEMENT WITH FACILITIES PLAN

When reviewing the design plans and specifications, the evaluator should have a clear understanding of the facilities plan and its relationship to the design. The engineer should include a statement with the design package concerning agreement with the facilities plan especially with regard to:

- Area for application
- Critical loading rate
- Degree of treatment
- Storage volume

The design should conform as closely as possible to the facilities plan; however, modifications may be necessary or desirable as the project is studied further, and more data become available. Reevaluation of the plan, in whole or in part, may also be necessary.

### A.1. MODIFICATIONS

Modifications and refinement of the facilities plan are often necessary and can occur for a variety of reasons. They may be the result of a pilot study, further detailed site investigations, or a change in project goals.

Modifications to any one system component should be evaluated relative to their effects on the entire system and on the other components. For example, a decision to change the type of crop grown in an irrigation system may be based on preapplication treatment considerations. The change in crops will, in turn, necessitate a reevaluation of such factors as loading rates, nutrient removals, storage requirements, manpower requirements, and economic considerations.

To demonstrate expected treatment results in special cases, such as for overland flow, pilot studies may be necessary. This should be a relatively rare occurrence for land-application approaches such as irrigation or infiltration-percolation. The extra cost of a pilot study and the subsequent delay of project implementation must be well justified.

If pilot studies have been conducted, summaries of results should be required either as a supplement to the facilities plan or as supporting material for the design plans and specifications. These results may form the basis of modifications or support to the facilities plan.

When departures from the original concept have been made for any reason, justifications, new data, and computations should be required. This information should be included in either a supplement to the facilities plan or as supporting material with the plans and specifications, and should be reviewed with respect to the applicable considerations from Parts I and II of this publication.

## A.2. REEVALUATION OF FACILITIES PLAN

In some cases, a complete reevaluation of the facilities plan may be necessary when changing conditions, new information, or unanticipated problems create doubts as to the suitability of the system. Further modifications or reconsideration of previously eliminated treatment alternatives may be required. Areas of primary concern include: changes in conditions and treatment requirements that have occurred during the interim period and results from any pilot studies.

Changes in conditions and treatment requirements may be the result of new federal or state regulations or changes in basin water-quality management plans (40 CFR 131) or areawide wastewater treatment plans (40 CFR 35. 1050). Areas that may be affected include: (1) both groundwater and surface-water discharge requirements, (2) public health regulations with regard to preapplication, crop selection, or application techniques, and (3) land-use or zoning regulations.

Major problems with the proposed system may be identified during pilot studies. Solution of these problems may be possible by changing design criteria, process equipment, or management techniques. On the other hand, the entire facilities plan may have to be reevaluated and another alternative pursued.

## Section B

## SITE CHARACTERISTICS

In this section, details concerning site characteristics that should be considered when reviewing the plans and specifications are discussed with respect to topography, soils, and geohydrology. In most cases, a considerable amount of data on site characteristics will have been collected and analyzed during the planning stage of the project and will have been included in the facilities plan (I-C.). Frequently, the scope and degree of detail of this information is sufficient for design purposes and it does not need to be repeated in material supplied to the evaluator. In other cases, additional information and more detailed analyses may be required. When this additional information is used as a basis for design, its submission – in the form of either a supplement to the facilities plan or as supporting material with the plans and specifications – should be required. Evaluation of this additional material should be with respect to considerations addressed in both this section and in Section I-C.

### B.1. TOPOGRAPHY

A fairly detailed analysis of the topography of the site and adjacent land will have been conducted during the planning stage. In the design stage, however, additional information may be required as plans are developed. Use of aerial or ground surveys may be required to produce detailed plans for earthwork and site preparation. The site topography, as altered by construction, earthwork, and field preparation, should be analyzed for drainage patterns and erosion potential.

### B.1.a. Site Plan

In almost all cases, a set of large-scale site plans will be required. The scale of the drawings will vary with the size and complexity of the project; however, 1 inch = 50 feet, with 2-foot contour intervals is considered reasonable for most projects. Features that should be included are:

- Topography of the site
- Property boundaries
- Application areas
- Transmission and distribution systems
- Buffer zones
- Drainage systems and surface water bodies
- Storage areas

- Preapplication treatment facilities
- Monitoring points, wells, and springs
- Roads, buildings, pumping stations, etc.

Additional plans may be necessary to show greater detail of certain features or a greater amount of surrounding land. They will often be required for drainage studies and for the exact location of transmission lines.

### B. 1. b. Effects of Adjacent Topography

The adjacent topography should be evaluated for its effects on the site, particularly with respect to drainage. Adjacent land characteristics that may potentially (1) add stormwater runoff to the site, (2) back up water onto the site, (3) provide relief drainage, or (4) cause appearance of groundwater seeps, should be identified. In most cases, the first two conditions are highly undesirable, and corrective measures, such as interceptor ditches or drainage systems, must be employed.

### B. 1. c. Erosion Prevention

The topography of the site and adjacent land should be evaluated for areas of potential erosion, and the plans should be checked for provisions for erosion control. The effects of both applied wastewater and storm runoff should be considered. Special consideration should be given to the period of construction and system startup, when vegetative cover may be lacking or not fully developed. Erosion control procedures are documented in a recent report for EPA [128].

### B. 1. d. Earthwork Required

Earthwork details should be presented for both (1) field preparation, and (2) facilities, such as transmission lines, storage, and roads. Earthwork required for field preparation may include:

- Clearing of existing vegetation and debris
- Leveling, sloping, or grading of application area
- Spreading or storage basin construction
- Construction of dikes, levees, etc.
- Drainage and collection ditches, and erosion-control measures

The amount of earthwork required will be highly varied and will be dependent on the type of system and the existing topography. For many systems, particularly those employing overland flow, earthwork may be one of the largest construction cost components. Where topsoil is shallow, it may be necessary to stockpile topsoil for redistribution after the grading of underlying soil has been completed.

### B. 1. e. Disposal of Trees, Brush, and Debris

A special consideration during construction and field preparation is the method of disposal for trees, brush, debris, and other cleared material. This may present a significant problem, particularly for projects in which large amounts of previously unused or uncultivated land are to be used. The most important concern is that of the environmental impact, especially if disposal is to be accomplished by burning. An acceptable method of disposal should be included in the specifications.

## B. 2. SOIL

For some land-application systems, the analysis of soil characteristics conducted during the planning stage will be sufficient for design purposes and reported material need not be repeated with the design package. Additional information that may be required for design is discussed in following subsections. Infiltration and percolation rates are discussed separately in the section on Design Criteria (II-C).

### B. 2. a. Soil Maps

Soil maps should be included with design plans for land-application systems, unless previously submitted in the facilities plan. Although the generalized SCS soil maps contain a large amount of useful data on soils, they may not be detailed or specific enough for design purposes. The use of soil maps for the presentation of soil data may be extremely helpful, particularly where soil characteristics are varied over the site. Existing soil maps may be used, or maps can be prepared showing variations in characteristics such as: (1) soil type, (2) infiltration and percolation potentials, (3) physical and chemical characteristics, and (4) soil depths.

### B. 2. b. Soil Profiles

A detailed description and analysis of the soil profile will frequently be necessary for design purposes, particularly if a large amount of percolation is planned, and where the effects of lower soil layers are of concern. Minimum soil profile depths to be evaluated by the designer, as suggested earlier (I-C) are:

- 2 to 5 feet (0.61 to 1.52 m) for overland flow
- At least 5 feet (1.52 m) for irrigation
- At least 10 feet (3.05 m) for infiltration-percolation

The required data may be obtained from SCS soil surveys, borings or test pits, or well-driller logs. If obtained from SCS surveys, the descriptions of the soil profiles will generally include: (1) the location on the site where the profile was determined, (2) mechanical classification, pH, salinity, and percent sodium for each layer of soil encountered, (3) the depth of each layer, and (4) the percolation rate expected. Additional soil analyses from the series of tests suggested in I-C.2.c.1 may also be required. In many cases, soil profiles must be determined at a number of locations, particularly where soil characteristics are varied over the site. Analysis of the underlying soil should be conducted primarily with respect to those properties affecting renovation capabilities and percolation potential (permeability for those soil layers that are to be saturated). The need for soil amendments such as lime or fertilizer in the topsoil should be determined.

## B.3. GEOHYDROLOGY

The extent to which geohydrologic conditions should be considered during design will be dependent on the method of application to be employed and the type and severity of conditions known to exist. Generally, a detailed analysis of the site geology and groundwater conditions will be necessary for infiltration-percolation and high-rate irrigation systems, where large amounts of percolating water may greatly affect the groundwater. When potentially adverse conditions, such as geologic discontinuities, perched water, and seasonally high water tables, are indicated during the preliminary site investigation, additional analysis and consideration may be necessary during design.

### B.3.a. Map of Important Geologic Formations

A map of the important geologic formations underlying the site will be necessary where the formations may possibly affect the renovation of the percolating wastewater or the groundwater flow. Formations and features that should be shown on the maps or drawings that accompany the design package, when of significance, include:

- Depth to bedrock
- Lithology of bedrock
- Outcrops
- Glacial deposits
- Discontinuities, such as faults, joints, fractures, and sinkholes

When the underlying geologic conditions are relatively uniform, or when they are of little significance a map will usually not be necessary.

### B.3.b. Analysis of Geologic Discontinuities

The presence of geologic discontinuities, such as faults, joints, fractures, and sinkholes, is cause for special concern because short-circuiting of the percolating wastewater may occur. In most cases, sites where geological formations contain severe discontinuities should have been eliminated from consideration during the preliminary site investigation; however, acceptable land-application systems may be possible where: (1) short-circuiting of the percolate to the groundwater occurs after sufficient renovation, and (2) the condition of the discontinuity is not expected to worsen. The first condition can usually be met if a sufficient soil horizon exists above the discontinuity. Suggested minimum depths of the soil horizon above discontinuities are:

- 2 feet (0.61 m) for overland flow
- 5 feet (1.52 m) for irrigation
- 15 feet (4.57 m) for infiltration-percolation systems

With regard to the second condition, the probability that discontinuities will not be aggravated as a result of the land-application system must be assessed. When the site is underlain with limestone, discontinuities may well be aggravated. Existing sinkholes may be enlarged and new ones created as a result of the percolating wastewater.

### B.3.c. Groundwater Analysis

A detailed groundwater analysis will be necessary for design purposes, particularly for infiltration-percolation and high-rate irrigation systems. Factors that should be considered include: (1) existing quality of the groundwater and required quality of the percolate with respect to the BPT requirements for groundwater protection [3], (2) the extent of the recharge mound, (3) the need for underdrainage or pumped withdrawal, (4) the probability of the groundwater reaching levels that may interfere with efficient renovation (see I-C.2.e.1), (5) the effects of the system on direction and rate of groundwater flow and, (6) the degree of monitoring required. Potential adverse effects on the groundwater identified in the planning stage (I-F) should be reviewed, and means of control employed in the design.

## Section C

## DESIGN CRITERIA

The following factors should be considered in the design of a land-application system:

- Climatic factors
- Infiltration and percolation rates
- Loading rates
- Land requirements
- Application rates and cycle
- Crops
- System components
- Flexibility
- Reliability

It must be reemphasized that land-application system designs are site-specific and that design criteria must be based on the conditions of the particular site. In evaluating a design, the following points should be considered:

- The validity of design assumptions
- Compatibility with site conditions
- Completeness and degree of detail
- Ability to meet project objectives

In most cases, design criteria used as a basis for the plans and specifications will have been included in the facilities plan (I-E); however, greater detail, refinements, and modifications will often be necessary. Submission of supporting material for these refinements and modifications – either along with the plans and specifications or by means of a supplement to the facilities plan – should be required. This supporting material should be reviewed with respect to considerations addressed in this section and Section I-E., and then used as a basis for evaluating the plans and specifications. Sample listings of design criteria for irrigation, infiltration-percolation, and overland flow systems are included in Appendix D.

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## C.1. CLIMATIC FACTORS

Design assumptions must be reviewed with regard to each climatic factor. For example, if a particular system is to be designed so that no runoff from the site results from a 5-year storm, the intensity of that storm should have been determined and used as a basis for design. Climatic conditions must usually be considered with respect to precipitation, temperature, and wind.

### C.1.a. Precipitation

Precipitation, including rainfall, snow, and hail, will affect a number of design components such as: (1) liquid loading rates, (2) storage requirements, and (3) drainage system requirements. Precipitation data that will normally be required for design include:

- Total annual precipitation
- Maximum and minimum annual precipitation
- Monthly distribution of precipitation
- Storm intensities
- Effects of snow

C.1.a.1. Total Annual Precipitation – The total annual precipitation used for design purposes should normally be estimated from a frequency analysis of precipitation data over the period of record (I-C.2.a). In most cases, precipitation from a wetter-than-normal year must be assumed, particularly where liquid overloading of the system may be a potential problem. The total annual precipitation for the wettest year in 10 is suggested as reasonable for most systems, although the wettest year in 50 or higher may be desirable for estimating storage requirements.

C.1.a.2. Maximum and Minimum Annual Precipitation – In many cases, the maximum and minimum annual precipitation on record will be of significance. For example, a considerable difference between the design precipitation and the maximum precipitation on record may require that special provisions for drainage be made. Minimum amounts of precipitation may be of interest for certain irrigation systems, where design liquid loadings are low and the applied wastewater alone would not be sufficient for optimum vegetation growth. In such cases, a plan for reduced crop acreage or for supplemental irrigation water should be included.

C.1.a.3. Monthly Distribution of Precipitation – The distribution of precipitation over the year should be expressed as the amount of precipitation per month for the design year. Seasonal variations in application rates and storage requirements will be based on an analysis of the monthly distribution.

C.1.a.4. Storm Intensities – Storm intensities, normally expressed in inches/hour, must be estimated for the design of drainage and runoff collection systems. This estimation will normally be made on the basis of a frequency analysis and a design storm event will be selected and analyzed for the amount of runoff.

C.1.a.5. Effects of Snow – In regions where accumulation of snow is probable, the effect of snow conditions must be evaluated. Important data that may be required include: (1) total amount of snowfall, (2) maximum expected depth, and (3) the period of snow cover.

### C.1.b. Temperature

Temperature, through its influence on various renovation mechanisms and on plant growth, will affect liquid loading rates and the period of operation. Temperature data that may be necessary for design include:

- Monthly or seasonal averages and variations
- Length of growing season
- Period of freezing conditions

C.1.b.1. Monthly Averages and Variations – The range of temperatures that prevail at the site should be expressed in terms of monthly or seasonal averages and variations. In many cases, where cold weather may require a reduction or cessation of application, design temperatures should be based on a frequency analysis of colder-than-normal conditions.

C.1.b.2. Length of Growing Season – An estimation of the length of the growing season will be necessary for irrigation and overland flow systems and for those infiltration-percolation systems with vegetated basin surfaces. Because the length of the season will vary with the crop, the Agricultural Extension Service should be consulted.

C.1.b.3. Period of Freezing Conditions – The period when application of wastewater must be reduced or ceased as a result of freezing conditions must be estimated. Freezing conditions may include the period when the ground is frozen or the period between the first and last frosts of the season.

### C.1.c. Wind

For spray application systems, an analysis of the wind will be necessary for design. Wind conditions that require a reduction or temporary cessation of application should be determined with respect to velocity and direction. The frequency and duration of those conditions should then be estimated by means of a frequency analysis.

## C.2. INFILTRATION AND PERCOLATION RATES

Infiltration and percolation rates are included in this section rather than the previous one (Site Characteristics) because of their direct relationship to the design of the system. Design rates must be determined for use in subsequent design calculations such as application rates and drainage system requirements.

### C.2.a. Design Rates

Design infiltration and percolation rates should be determined from data obtained in the preliminary site investigation (I-C.2.c.2) and from additional studies where required. Other soil characteristics (II-B.2) and geohydrologic factors (II-B.3) must be evaluated for their effects on percolation rates. Conditions that may be expected to periodically inhibit infiltration or percolation, such as cold weather or prolonged periods of soil wetting, should be assumed in the determination of design rates. Requirements for periodic drying or resting periods should be included.

### C.2.b. Basis of Determination

The basis used to determine the design infiltration and percolation rates, and the results of any studies or analyses involved, should be evaluated. Design rates should be based on at least one or more of the following analyses or consultation services:

- Analysis by Agricultural Extension Service or soil specialists
- Analysis of soil borings and profiles
- Analysis of SCS soil surveys
- From farming experience
- From results of pilot studies

## C.3. LOADING RATES

Loading rates for the liquid applied and the major constituents of the wastewater will form the basis for the design determination of land requirements, application rates, and crop selection (for irrigation and overland flow). Loading rates computed in the preliminary planning stage (I-E.1) should be reviewed and possibly revised to reflect changes in the wastewater characteristics or in the application rates.

### C.3.a. List of Loading Rates

Loading rates that form the basis of the design are to be included in the design criteria (see Appendix D) for the specific land-application system.

Elements or constituents of concern should include any which may potentially cause short- or long-term problems for the specific system, or whose concentrations in the renovated water may reach or exceed water-quality standards.

### C.3.b. Critical Loading Rate

The loading rate identified in the planning stage as being critical (I-E.2.a.) will be used in the determination of the application area and other design factors, such as crop selection. The critical loading rate should be highlighted with an asterisk on the design criteria listings (Appendix D).

## C.4. LAND REQUIREMENTS

Land requirements must be identified for each of the following components:

- Application area
- Buffer zones
- Storage
- Preapplication treatment, buildings, and roads
- Future and emergency needs

Land for each component should be designated on the site plan. Additionally, methods of determination and calculations should generally be reviewed, particularly those for the application area.

The land required for the direct application and treatment of the wastewater will be calculated from the design critical loading rate as described in paragraph I-E.2.a. A distinction should be made between the wetted and field acres where the distinction is significant, as is the case for all overland flow and some irrigation systems. Individual plots or basins that are to be operated as units in a rotation cycle should be identified and numbered.

## C.5. APPLICATION RATES AND CYCLE

The design application rates and the schedule of application periods should be reviewed and related to the determination of land and storage requirements and to the design of the distribution system (I-C.7.d.). Factors and considerations relating to their derivation are discussed below.

### C.5.a. Annual Liquid Loading Rate

The design annual liquid loading rate (ft/yr) should be identified (II-C.3.). All application rates with respect to smaller units of time (e.g., in./wk) should be derived from or be compatible with the annual loading.

### C.5.b. Length of Operating Season

The length of the operating system may vary from year-round for many infiltration-percolation systems to as little as 5 or 6 months for some irrigation systems.

### C.5.c. Application Cycle

The application cycle, or the combination of application and resting periods, should be defined in the form of an operating schedule. The length of the cycle and the ratio of wetting to drying depends on site-specific factors (I-E.1.d.) and may include seasonal variations. Common cycle lengths are:

- 1 week for irrigation, with a range from 2 days to 6 weeks
- 1 day for overland flow, with a range from 12 hours to 2 days
- 3 weeks for infiltration-percolation, with a range from a few days to a month

C.5.c.1. Application Period and Rates – The application or wetting period of the cycle should be listed along with the rate of application. Application rates should normally be expressed in terms of quantity of wastewater applied per cycle, and for spray applications the hourly rate should be listed. The latter rate is particularly important for spray systems because high applications may be damaging to the soil surface.

C.5.c.2. Weekly Application Rates – When the application cycle is other than one week, the additional inclusion of the average weekly rate may be helpful for evaluation. Weekly rates are often used as standards for comparison of similar systems and frequently appear in the literature.

C.5.c.3. Resting or Drying Period – Resting or drying periods are necessary to reestablish aerobic conditions. They should be included as an integral part of the application cycle. Optimum resting periods range from one day or less for some irrigation and overland flow systems up to 20 days for some infiltration-percolation systems. In many cases, longer resting periods are required during the winter months.

**C.5.c.4. Rotation of Plots or Basins** – To maintain continuous operation and a steady usage of effluent, it is usually advisable to subdivide the application area into a number of independent plots or basins. Wastewater can then be applied to a portion of the area while the remainder is rested or dried. Provision for plot or basin rotation should be included in the plans.

## C.6. CROPS/VEGETATION

A description of the crops or vegetation to be grown will be required in the facilities plan for all systems in which vegetation is to be an integral part of the treatment system. This includes all irrigation and overland flow systems, and those infiltration-percolation systems in which the infiltration surfaces are to be vegetated. Evaluations of potential crops that were conducted during the planning stage (I-E.3.) should be reviewed, and important crop characteristics and requirements that were used as a basis for design should be noted. When applicable, the following items should be considered:

- Compatibility of the crop with site characteristics and design loading rates
- Nutrient uptake
- Cultivation and harvesting requirements
- Suitability for meeting health criteria

## C.7. SYSTEM COMPONENTS

A large portion of the plans and specifications will be devoted to the system components, such as:

- Preapplication treatment facilities
- Transmission facilities
- Storage facilities
- Distribution system
- Recovery system
- Monitoring system

Design considerations and parameters developed in the planning stage should be reviewed when applicable. Detailed plans for each component will be required and should be evaluated with respect to the considerations listed at the beginning of this section.

### C.7.a. Preapplication Treatment Facilities

Detailed plans of the preapplication treatment facilities will be necessary in almost all cases, except those few in which preapplication treatment is not required or existing facilities have been determined to be adequate. In many cases, plans for additions or modifications to existing facilities may be all that are required. In all cases, the expected treatment performance of the facilities must be evaluated in light of the requirements established in the planning stage (I-E.5.).

### C.7.b. Transmission Facilities

Detailed plans of the transmission facilities to the site, including piping and pumping facilities, will be required. They should be designed and reviewed in accordance with conventional engineering standards, because they will rarely differ from transmission facilities designed for conventional treatment systems. Consideration must be given to factors such as adequate cover over the pipe for protection, and provisions for flexible joints where the pipe is attached to rigid structures. In addition, consideration must also be given to the purchase and control of easements.

### C.7.c. Storage Facilities

In almost all cases, some sort of storage facilities will be necessary, and detailed plans for them will be required. If storage is to be provided for winter flows and storage requirements are high, construction of storage facilities will often be one of the major design components. The design volume should be based on the storage requirements determined during the planning stage (I-E.4.). The plans should be evaluated with respect to capacity and control of potential problems, such as the growth of unwanted aquatic life, odors resulting from anaerobic conditions, and with respect to structural considerations, such as embankment slope stability. Storage facilities must include pump-back provisions and adequate freeboard, and it may possibly be necessary to seal them to prevent percolation, depending upon groundwater conditions.

### C.7.d. Distribution System

The distribution system may vary in complexity from systems employing simply gravity flow to infiltration basins to highly complex fixed spray irrigation systems. Standard texts on irrigation [155, 184] provide much information on the design of all types of distribution systems, which may be useful to the reviewer. Potential problems, such as the clogging of nozzles with suspended solids and the susceptibility of above-ground piping to damage by farm machinery, should be anticipated, and mitigation provisions reviewed.

**Spray Systems** — Distribution for spraying is through pressure pipes or laterals that run from the transmission main into the field. Spray distribution systems may be solid set, buried; solid set, portable; mechanically-moved laterals, such as the side-roll wheel or end-tow type; or continuously moving units such as center pivot systems [114]. Sprinkler irrigation handbooks [114, 115, 155] should be consulted for hydraulic design information. Special emphasis should be given to the potential problems associated with risers, which are often susceptible to damage from a number of causes.

**Surface Distribution Systems** — For flood or ridge and furrow systems, distribution may be by means of open ditches, buried pipe with riser outlets, or gated pipe. More detailed information may be found in Zimmerman [184].

**Drainage of Lines** — Drain valves are necessary for most distribution systems to prevent (1) anaerobic conditions from occurring during nonapplication periods, and (2) freezing and breaking of pipes in cold climates. Drain valves should be located at all low points in the system with gravel or tile drains to accept the draining water.

**System Controls** — A schematic diagram of system controls including piping, pumping, valves, timers, and alarms is necessary. Valve operation and control may be automatic or manual or provisions may be made to operate under either type of control.

### C.7.e. Recovery System

Detailed plans should be submitted of any recovery system that is to be employed, such as: underdrainage, pumped withdrawal, or collection of runoff from overland flow systems. It should be evaluated with respect to recovery objectives, site characteristics, and liquid loading rates. Much useful information on the design of recovery systems may be found in *Drainage of Agricultural Land* [38], and in Bouwer [18, 19].

In cases in which natural drainage channels traverse the site some runoff control features may be required. For irrigation systems these features would be designed for system protection and realiability. Features could entail small dams, reservoirs, or diversion structures to collect or divert partially treated effluent and prevent it from entering surface waters. The extent to which runoff resulting from storms must be retained depends upon the water quality objectives for the surface water, nonpoint source discharge control practices in the hydrologic basin, and the nature and magnitude of the environmental degradation that might result from the discharge.

### C.7.f. Monitoring System

Some form of monitoring system will be required in all cases and should be described in detail in the Operation and Maintenance Manual. Plans for physical facilities, such as monitoring wells, sampling taps, and metering equipment, however, should be included in the design and should reflect the monitoring requirements specified in the preliminary plans (I-E.6.c.).

## C.8. DESIGN FLEXIBILITY

The design plans and specifications should be evaluated for flexibility with respect to:

- Provisions for system expansion
- Provisions for system modification
- Interconnections and partial isolation

Specific flexibility features identified in the wastewater management plan (I-E. 8.) should be incorporated in the design.

### C.8.a. Provisions for System Expansion

Provisions for both planned and unplanned expansion should be incorporated in the design. Staged construction will often be employed over the life of the system to provide for planned expansion. In other cases and for unplanned expansion, components may be designed for additional capacities or so that their capacities may be easily increased. Special consideration should be given to critical components – such as: land availability; and storage, preapplication treatment, and transmission capacities – which may be easily expandable only up to a certain limit.

### C.8.b. Provision for System Modification

Various modifications to the system can usually be expected to occur during the life of the system and if possible, should be anticipated in the design. Generally, these modifications will be the result of:

- Knowledge gained through operating experience
- Changes in conditions or treatment requirements
- Technological advances

Design factors, such as loading rates, and physical equipment, such as preapplication treatment and distribution facilities, are among the items that may be subject to modification.

### C.8.c. Interconnections and Partial Isolation

Features, such as interconnections and partial isolation systems, that may add to the flexibility of operation should be included in the design when practicable. Various interconnections within and between the transmission system, preapplication treatment facilities, storage facilities, and distribution system are necessary so that components can be isolated for repair or maintenance. The design should also include provisions to allow the operator to modify operating procedures for special conditions, and apply effluent to certain areas only.

## C.9. RELIABILITY

The Technical Bulletin on Design Criteria for Mechanical, Electrical, and Fluid Systems and Component Reliability [35] establishes minimum standards of reliability for three classes of wastewater treatment works. The classes are related to the consequences of degradation of the effluent quality on the receiving navigable waters. Class I involves discharge to navigable waters that could be permanently or unacceptably damaged by effluent that was degraded in quality for only a few hours. Reliability measures for this class include backup requirements for most unit processes. Class II relates to navigable waters that would not be permanently or unacceptably damaged by short-term effluent quality degradations, but could be damaged by continued (on the order of several days) degradation. Class III involves navigable waters not otherwise classified as Reliability Class I or II [35].

Land-application systems that produce an effluent with a point-source discharge would have to attain a reliability commensurate to that of conventional treatment and discharge systems discharging to Class I, II, or III navigable waters. The degree of reliability required of land-application systems will depend on the severity and consequences of environmental degradation or health effects (I-F.1 and F.2). The California standards (Appendix E) relate reliability measures for irrigation systems to the degree of public contact with the treated effluent and the nature of the crop grown.

Various means of ensuring the reliability of the system, including factors of safety, backup systems, and contingency provisions, are discussed in the following paragraphs. An important additional reliability factor is the proper operation and maintenance of the system, which is discussed in Part III. General reliability requirements for all treatment systems are included in Federal Guidelines for Design, Operation and Maintenance of Waste Water Treatment Facilities [50].

### C.9.a. Factors-of-Safety

Reasonable factors-of-safety must be included in design components whose normal operation limits, if exceeded, might result in serious adverse effects or impairment of system efficiency. Components that may require factors-of-safety in their design include: loading and application rates, and the capacities for storage, transmission, and preapplication treatment. The magnitude of the factors-of-safety to be employed will vary with the system and will depend on a number of factors, such as: the severity of potential adverse effects, and degree of certainty of design assumptions. When employed, they should be indicated and justified by the engineer.

## C.9.b. Backup Systems

Backup systems or standby units must be provided for critical elements of the system to preclude system failure resulting from:

- Loss of power supply
- Equipment failure
- Failure of a preapplication treatment unit
- Maintenance requirements

Elements that should be provided with backup systems include power sources, pumping facilities, and preapplication treatment units (particularly chlorinators). Interconnections and flexibility of pumping and piping to permit rerouting of flows will often be necessary also.

## C.9.c. Contingency Provisions

Provisions must be made in the design for specific, unusual, or emergency conditions that may occur at the site, such as:

- Equipment or unit failure
- Natural disasters (floods, earthquakes, etc.)
- Severe weather
- Unexpected peak flows

The system must be evaluated to determine whether it can be operated satisfactorily under these conditions. Provisions should be included to allow the resumption of normal operation, such as emergency pumping or additional storage capacity.

## Section D

## EXPECTED TREATMENT PERFORMANCE

The expected treatment performance must be evaluated with respect to both (1) removal efficiencies for major constituents, and (2) remaining concentrations in the renovated water. It should be predicted realistically based on the method of application, degree of preapplication treatment, site characteristics, and design parameters. Fluctuations in performance during loading cycles or as a result of seasonal climatic variations, should be considered.

### D.1. REMOVAL EFFICIENCIES FOR MAJOR CONSTITUENTS

The removal efficiencies, or the percentage reduction in concentration of each of the major wastewater constituents must be estimated. Removal efficiencies, based on data derived from operating systems, that may be expected for well-designed and properly maintained, irrigation, overland flow, and infiltration-percolation systems are given in Table 12. Predicted efficiencies should be estimated for each constituent, and a description of the removal mechanism, particularly for constituents such as nitrogen, where removal efficiencies are highly variable, should be included either in the project report or a supplement. The values in Table 12 are presented for evaluation, not design purposes. Design values must be developed on a case-by-case basis. Factors such as changing climatic conditions or changing operating procedures that may cause fluctuations or permanent changes in the removal efficiencies should be identified. Expected long-range changes, such as those resulting from exhaustion of the ion-exchange capacity of the soil, should be identified and provisions made for soil amendment additions, upgrading or preapplication treatment, or cessation of application.

Table 12. REMOVAL EFFICIENCIES OF MAJOR CONSTITUENTS FOR MUNICIPAL LAND-APPLICATION SYSTEMS

| | Removal efficiency, % | | |
|---|---|---|---|
| | Application method | | |
| Constituent | Irrigation | Overland flow | Infiltration-percolation |
| BOD | 98+ | 92+ | 85-99 |
| COD | 95+ | 80+ | 50+ |
| Suspended solids | 98+ | 92+ | 98+ |
| Nitrogen (total as N) | 85+ | 70-90 | 0-50 |
| Phosphorus (total as P) | 80-99 | 40-80 | 60-95 |
| Metals | 95+ | 50+ | 50-95 |
| Microorganisms | 98+ | 98+ | 98+ |

Expected removal efficiencies must be determined for each individual case based on the wastewater characteristics, site characteristics, and specific design features. For example, consider phosphorus removal for an overland flow system. Assuming that the total concentration after preapplication treatment is known, what removal efficiency can be expected? Without pilot work to serve as a basis for estimation, a review of the literature must be used. Representative reports dealing with phosphorus removal include those by Law [84], Kirby [76], Thomas [164], and Hunt [67]. To properly assess the expected removal, comparisons must be made of the systems described in the literature with the system in question on the following points:

- Total concentration applied to the land
- Total annual loading, lb/acre/yr
- Percentage of applied wastewater appearing as runoff
- Soil type
- Evapotranspiration
- Amount of percolation
- Crop type and uptake of phosphorus
- Was the crop removed from the field?
- Application cycle
- Length of the runoff slope
- Amount of rainfall during period of measurement

Obviously, few of the conditions will be comparable so that some engineering judgment will be required. Each removal mechanism (II-E.1.c.), such as crop uptake, microbial uptake, and fixation by the soil, must be investigated and the expected removals estimated.

The process of determining expected removal efficiencies can often be complex. The degree of detail expected in deriving these estimates will depend on the impact of the constituent on the environment and the concentration required in the renovated water.

## D.3. REMAINING CONCENTRATIONS IN RENOVATED WATER

The remaining concentrations of the major constituents in the renovated water should be determined from concentrations of the wastewater applied and the predicted removal efficiencies. They should be compared to the concentrations required for the receiving waters, either groundwater or surface water, or to requirements for further reuse. Generally, to be acceptable, the concentrations should be well within the limits of stated requirements.

# PART III

# OPERATION AND MAINTENANCE MANUAL

## Section A

## EPA – CONSIDERATIONS FOR PREPARATION OF OPERATION AND MAINTENANCE MANUALS

Operation and maintenance manuals should generally be prepared in accordance with the suggested guidelines presented in the EPA publication Considerations for Preparation of Operation and Maintenance Manuals [61], which is hereafter referred to as the "Considerations Manual." They should be reviewed and evaluated by means of the checklist included in the Considerations Manual, and with regard to special considerations for land-application systems presented in this and the following sections.

Discussion of the information that should be included in operations and maintenance manuals for land-application systems is presented in the following subsections by suggested chapter titles. Detailed discussion of information concerning operating procedures, monitoring, and impact control is contained in Sections B, C, and D. The format suggested herein and in the Considerations Manual is intended to be flexible and may be modified to fit the particular system at hand. The uniqueness of many land-application systems must be reflected in the operation and maintenance manuals, and greater-than-normal emphasis must be placed on their preparation, especially in the explanation of the unique aspects.

### A.1. INTRODUCTION

The introduction to an operation and maintenance manual should include:

- A manual user guide
- Summaries of operation and managerial responsibilities
- Description of the treatment concept employed and treatment requirements
- Explanation of flow patterns

A discussion of the contents of the introductory chapter and examples showing the scope of information that should be included is contained in the Considerations Manual.

The description of treatment requirements should highlight requirements with respect to groundwater including meeting requirements of BPT for groundwater protection, as well as effluent limitations for that portion of the renovated water that may be recovered.

In many cases, a brief summary of basic land-application principles may be helpful, particularly for users of the manual who have had experience only with conventional treatment systems.

## A.2. PERMITS AND STANDARDS

The chapter on permits and standards should include:

- Discharge permit and permit requirements (for point-source discharges)
- Reporting procedures for spills of raw or inadequately treated sewage
- Water-quality standards

The suggested contents of the chapter are discussed in the Considerations Manual and are applicable, at least in part, to most land-application systems. Special consideration must be given to standards relating to the groundwater.

## A.3. DESCRIPTION, OPERATION AND CONTROL OF WASTEWATER TREATMENT FACILITIES

This chapter will be the heart of the operation and maintenance manual in which each component of the land-application system is described, and the operation and control procedures are detailed. The chapter should be subdivided by components, with the following subdivisions suggested for land-application systems in place of those suggested on page 56 of the Considerations Manual:

- Preapplication treatment facilities
- Transmission system
- Storage facilities
- Application of effluent
- Soils and plants
- Recovery systems

The major system components should be subdivided into units to allow a thorough description and to aid in understanding the interactions of the various units.

Information that should be presented for each individual component includes:

- Description of component and major subcomponents
- Relationship to adjacent components
- Methods of control
- Startup
- Normal operation
- Common operating problems
- Alternate operation
- Emergency operations and failsafe procedures
- Monitoring and laboratory controls

The preceding list has been slightly modified from the one suggested in the Considerations Manual; however, the discussion and examples contained therein are generally applicable for land-application systems. It is expected that further modification will be necessary or desirable for various components of many systems.

Additional considerations pertinent to the content of this chapter are discussed in Sections B, C, and D.

### A.4. DESCRIPTION, OPERATION AND CONTROL OF SLUDGE-HANDLING FACILITIES

Sludge-handling facilities should be described and operating and control procedures should be outlined in this chapter. The extent and significance of the chapter will be highly variable and will depend upon the method and degree of preapplication treatment to be employed. In many cases, the entire chapter may be unnecessary if sludge-handling facilities are not complex and are included in the previous chapter (III-A.3.).

## A.5. PERSONNEL

Personnel requirements should be discussed with respect to:

- Manpower requirements/staff
- Qualifications
- Certification

Consideration must be given to special skills and qualifications necessary for land-application systems, such as those relating to agricultural practices and groundwater monitoring. In all other respects, the discussion in the Considerations Manual is generally applicable to land-application systems.

## A.6. LABORATORY TESTING

The material to be presented on the laboratory testing program should generally include:

- The purpose of the sampling program
- The sampling schedule
- The list of operation/laboratory references
- Interpretation of laboratory tests
- Sample laboratory worksheets

The suggested format and discussion of the laboratory testing program contained in the Considerations Manual are applicable in most respects to most land-application systems; however, a wider range of tests, such as those to determine the uptake of certain constituents by crops, and various soils tests are often necessary. Additional specific considerations for land-application systems are discussed later in Section C.

## A.7-A.13. REMAINING MANUAL CHAPTERS

The remaining chapters to be included in the operation and maintenance manual will normally deal with:

A.7. Records

A.8. Maintenance

A.9. Emergency Operating and Response Program

A. 10. Safety

A. 11. Utilities

A. 12. Electrical System

A. 13. Appendixes

Each is discussed in detail in the Considerations Manual, and is generally applicable to all wastewater treatment systems, including those employing land application. Modification of the suggested format may be necessary or desirable in many cases so that the manual may be tailored to fit each system.

## Section B

## OPERATING PROCEDURES

A number of special topics concerning operating procedures for land-application systems are discussed in this section, including:

- Application of effluent
- Agricultural practices
- Recovery of renovated water
- Storage
- Special problems and emergency conditions

Operating procedures for system components that are generally common to conventional systems, such as those for preapplication treatment facilities, are not discussed.

### B.1. APPLICATION OF EFFLUENT

The procedures for the application of effluent to the land must be clearly defined because many distribution systems will be unique and the operators must be able to vary the application in response to environmental changes. Descriptions of the application system and the operating procedure should be included in Chapter 3 of the operation and maintenance manual. Considerations relating to both the distribution system and the schedule of application are discussed in the following paragraphs.

### B.1.a. Distribution System

The distribution system should be described and the operating and control procedures outlined in a manner similar to the other components, as described previously in Subsection III-A.3. For most systems, including those for overland flow and infiltration-percolation facilities, operating procedures will be based primarily on standard irrigation practices. Standard references on irrigation [115, 155, 184] should be consulted along with manufacturer's operating instructions. Valve sequences, operating pressures, startup and shutdown procedures should be detailed. Solution of typical problems that may be encountered with the distribution of wastewater, such as the clogging of nozzles with suspended solids, should be included.

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### B.1.b Schedule of Application

Because this portion of the manual will be referred to frequently, it is imperative that application schedule details be presented clearly. Effluent application schedules should be presented in terms of the rates, periods of application and resting, and seasonal variations as developed in the design (II-C.6.). Also included should be the sequence of rotation of plots or basins, seasonal variations in rotation, and descriptions of conditions that may require temporary cessation of application. The range of acceptable application rates and ratios of resting to wetting should be included as a guide to assist operators in making necessary operational changes.

## B.2. AGRICULTURAL PRACTICES

Operating procedures relating to agriculture will play a major role in the operation of irrigation systems, and a lesser but still significant role for overland flow and infiltration-percolation systems. Procedures regarding agricultural practices should normally be described under "soils and plants" in Chapter 3 of the manual (III-A.3.). Factors relating to agriculture that are discussed in this section include:

- Purpose of the crop
- Description of crop requirements
- Planting, cultivation, and harvesting

### B.2.a. Purpose of the Crop

The purpose for which vegetation is to be grown should be stated clearly in the manual so that the system may be operated to best achieve that goal. The primary consideration of importance to the operator is whether optimization of crop yields or maximization of renovation and effluent application is to be emphasized. Other desired results, such as increased infiltration rates, and combinations of desired results should also be described.

### B.2.b. Description of Crop Requirements

Crop requirements should be specified with respect to:

- Water requirements and tolerance
- Nutrient requirements
- Necessary soil amendments

- Climatic conditions
- Public health requirements

Methods for evaluating crop performance with respect to these requirements and operating procedures to ensure that the requirements are met should be described.

### B.2.c. Planting, Harvesting, and Cultivation

Procedures should be described for all aspects of crop management, including: planting, harvesting, and cultivation. A general schedule for crop management should be included, and methods of determining optimum dates for planting, harvesting, and cultivation should be explained. Related events and requirements, such as the requirement for ceasing application a certain number of days prior to harvesting, should also be described.

## B.3. RECOVERY OF RENOVATED WATER

Operating procedures for the recovery of renovated water should be described for all systems which employ: (1) pumped withdrawal, (2) tile drainage, or (3) collection of runoff from overland flow. Detailed considerations for the operation and maintenance of recovery systems are presented in various references, most notably in Drainage of Agricultural Land [38]. Standard procedures, operating parameters, and methods of control should be listed for both normal flow conditions and peak flows. Quality monitoring and discharge requirements should also be listed. Any point source municipal discharge requires a permit under the NPDES program. Systems built with EPA construction grant funds are controlled by conditions of the construction grant. Special procedures for unusual or emergency conditions, such as the collection and storage of contaminated storm runoff for later application, should be described.

## B.4. STORAGE

Storage of effluent to be applied will often present special problems for land-application systems, in that large volumes of water must frequency be stored for long periods of time. For this reason, procedures for the operation of the effluent storage facilities should be described in detail. If the potential for special problems, such as odors resulting from anaerobic conditions or the growth of unwanted aquatic life exists, special procedures and methods of control should be included.

## B.5. SPECIAL PROBLEMS AND EMERGENCY CONDITIONS

Operating procedures for special problems and emergency conditions should be described in Chapter 9 of the manual. Design features with respect to flexibility (II-C.8.) and reliability (II-C.9.) will form the basis for any special operating procedures that may be required.

## Section C

## MONITORING

The monitoring requirements of a land-application system must receive special consideration, because of the wide variety and complexity of parameters and effects that should be analyzed. Requirements should be described with respect to each system component in Chapter 3 of the Operations and Maintenance Manual and with respect to laboratory testing in Chapter 6. If the monitoring requirements are complex, it may be appropriate to devote an entire chapter to the monitoring program or to expand Chapter 6 (Laboratory Testing) to include a description of the entire program.

In the following subsections, monitoring considerations that should be included in the operation and maintenance manual are discussed with respect to:

- Parameters to be monitored
- Monitoring procedures
- Interpretation of results

### C.1. PARAMETERS TO BE MONITORED

As in most conventional treatment facilities, concentrations of certain constituents should be monitored at various stages in the treatment process. Generally, for land-application systems, water quality should be analyzed at the following stages:

- Influent into the system
- Following preapplication treatment
- Following storage
- Groundwater
- Recovered water (from pumped withdrawal, underdrains, or collected runoff from overland flow)

Water-quality parameters that must be analyzed at each of these stages will vary. Monitoring at the first three stages will be primarily for system control and optimization purposes. Consequently, the parameters to be analyzed will be those identified as indexes of previous treatment efficiency, and those that may indicate the requirement for operational adjustments during subsequent treatment processes.

Water quality parameters that should be analyzed in the groundwater are those: (1) given in the proposed Criteria for Water Quality [29], or any revisions thereof, (2) required by state or local agencies, (3) given in the report on Alternative Waste Treatment Management Techniques for Best Practicable Waste Treatment [3] and any revisions thereof, and (4) necessary for system control. Monitoring requirements for recovered water will depend upon the disposition of that water. If the water is to be discharged, the parameters to be analyzed must include those required in the NPDES permit. If the water is to be reused, analysis of additional parameters may be required by cognizant public health agencies.

In addition, a variety of other system effects, in some cases, should also be monitored both at the site and in the surrounding area. These include:

- Groundwater levels and direction of flow (I-C.2.e.)
- Physical and chemical soil characteristics (I-C.2.c.1)
- Growth and production characteristics of crops or vegetation
- Various environmental effects (on adjacent land, animal and insect lives, etc.)

## C.2. MONITORING PROCEDURE

Detailed procedures for monitoring must be described for each aspect of the monitoring program, including the location of sampling points, and the frequency of sampling. Descriptions of the appropriate laboratory tests, where the test is to be performed, and by whom, should be included in Chapter 6 for each parameter that is to be monitored. The type of scope of information that is being sought should be described. Blakeslee [14] presents some suggested procedures for groundwater monitoring.

## C.3. INTERPRETATION OF RESULTS

Charts, graphs, ranges of satisfactory values, and upper limits requiring remedial action must be included for each major parameter where applicable. A range of results that are to be expected during normal operation should be indicated, along with those results that may be an indication of a malfunction in the system. Whenever possible, indications of malfunctions should be related to appropriate measures of control and corrective procedures (III-D.3).

During the initial years of operation, monitoring results should be analyzed and reviewed with the designer or various specialists. For example, interpretation of groundwater data by a geohydrologist may be necessary. Results that should be referred to personnel outside the normal operating staff should be identified.

## C.4. SURVEILLANCE AND REPORTING

Those results which relate directly to NPDES permits or other requirements should be specifically noted, as should results which come under the surveillance of various agencies such as state or local water resource boards or public health agencies.

## Section D

## IMPACT CONTROL

An important consideration in the review of the operation and maintenance manual is whether the control of potential adverse effects has been adequately addressed. Each potential adverse effect that was identified in the facilities plan and environmental assessment (I-F.) should be considered. Aspects of impact control that should be included are:

- Description of possible adverse effects
- Indexes of critical effects
- Methods of control
- Methods of remedial action

### D.1. DESCRIPTION OF POSSIBLE ADVERSE EFFECTS

All possible adverse effects of the system, including environmental, public health, social, and economic effects that were previously identified in either the planning or design stage should be identified and described. The introductory section of Chapter 3 of the manual is suggested as a reasonable place to present this information. In addition, possible adverse effects that may result from any one particular component of the system should be discussed in Chapter 9.

### D.2. INDEXES OF CRITICAL EFFECTS

Critical effects of a treatment system are those adverse impacts that must be controlled. Whenever possible, these indexes or first indications of critical effects should be described. They should be related to:

- Results of monitoring program
- Unusual or emergency conditions at the site
- Malfunction of various system components
- General observations of the operator

Provisions should be made so that the overall effects of the system based on all available information can be routinely monitored.

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## D.3. METHODS OF CONTROL

Methods of control should be described with respect to both normal operating controls and procedures, and adjustments or modifications to those procedures for each possible adverse effect. For example, elimination of standing water on the application area will normally be a standard procedure for most systems; however, it is also a method of control for mosquito breeding. Generally, each method of control should be described by component in Chapter 3 of the manual (III-A.3.) and should be specifically related to the effect it controls (III-D.1.), and to the indication of that effect (III-D.2.).

A convenient way of relating indications of critical effects to the appropriate methods of control is through the inclusion of a section on troubleshooting. Provisions should be included for the periodic reevaluation of control methods, particularly for the control of long-range effects. It should, however, be emphasized that land application is a dynamic process and that monitoring results will often be variable. Consequently, control measures that take trends into account should be employed.

## D.4. METHODS OF REMEDIAL ACTION

Remedial actions should be described for the various adverse effects that may result from system or component failure, accidents, and other unusual or emergency conditions. The objectives of these actions should be to prevent or minimize the adverse effects when emergency conditions are encountered, or to correct the situation once damage has been done. Depending on the system, necessary remedial actions may generally be described in Chapter 9 of the manual, Emergency Operating and Response Program (III-A).

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## Appendix B

## SELECTED ANNOTATED BIBLIOGRAPHY

In this appendix, 17 references that may be of value to the reviewer are listed and briefly described. The first three references provide an assessment of the state-of-the-art of land application and the fourth is an extensive annotated bibliography. Following the existing guidelines for operation and maintenance manuals are a group of three proceedings from recent conferences, each with a number of papers by various authors, in which a wide range of different topics are addressed. The remaining references include technical handbooks and individual papers which address a number of specific topics.

1. Pound, C.E. and R.W. Crites. Wastewater Treatment and Reuse by Land Application, Volumes I and II. Office of Research and Development, Environmental Protection Agency. August 1973.

In the summary report (Volume I), the results of a nationwide study conducted on the current knowledge and techniques of land application are given. Factors involved in system design and operation are discussed for irrigation, overland flow, and infiltration-percolation methods. In addition, evaluations are made of environmental effects, public health considerations, and costs.

In Volume II, detailed examinations are made of the literature and the selected sites visited. The relationship between climate and land application is examined. The state-of-the-art of land application of industrial wastewater is also reported. In addition, sections on cost evaluation, and land-application potential, and histories of several cases of irrigation abandonment are included.

2. Sullivan, R.H., et al. Survey of Facilities using Land Application of Wastewater. Office of Water Program Operations, Environmental Protection Agency. July 1973.

The results of a field survey of 63 municipal and 19 industrial systems in 1972 using irrigation with wastewater are presented in this report. The data collected are analyzed statistically using five climatic zones for the U.S. Abstracts from foreign experience and a state-by-state summary of health regulations are included. The appendix material is quite valuable since it includes all the raw data from the visits plus narratives and results of a parallel mail survey of 78 municipalities and 36 industries. Also appended are two excellent papers by Richard E. Thomas, soil scientist with the EPA.

3. Reed, S.C. Wastewater Management by Disposal on the Land. Special Report 171. Cold Regions Research and Engineering Laboratory. U.S. Army Corps of Engineers. May 1972.

This state-of-the-art review considers three land disposal techniques: spray irrigation, overland runoff, and rapid infiltration. Each technique is considered in detail, including such aspects as wastewater characteristics, water-quality goals, site conditions, operational criteria, and ecosystem response. The concept of renovative capacity is introduced in which the assumption is that there is a finite depth of soil in which major renovation occurs. The report was prepared by a multidisciplined team including hydrologists, geologists, climatologists, soil scientists, and sanitary engineers. The emphasis is on environmental responses to land application, but design components are discussed.

4. Land Application of Sewage Effluents and Sludges: Selected Abstracts. Office of Research and Development, Environmental Protection Agency. 1974.

This document is a combined annotated bibliography of a wide range of subject-matter related to application of sewage effluents and sludges to the land. Using the EPA document, Agricultural Utilization of Sewage Effluent and Sludge (prepared by Dr. Law) as a basis, inputs were received from (1) the state-of-the-art study by Pound and Crites [125], (2) the literature survey by Sullivan [160], (3) the Joint Conference at the University of Illinois (see No. 8), and (4) the state-of-the-art assessment of sludge spreading conducted by Battelle Columbus. These selected abstracts have been indexed by author, title, and location (for case studies). A strict division has been made between abstracts dealing with effluents and those dealing with sludges.

5. Green, R. L., G. L. Page, Jr., and W. M. Johnson. Considerations for Preparation of Operation and Maintenance Manuals. Office of Water Program Operations, Environmental Protection Agency.

In these guidelines, general considerations for the preparation of operation and maintenance manuals are presented, and a format for the manual is suggested. Each of the twelve chapters from the suggested format is then described in detail with respect to content, scope, and useful references. Checklists are included for evaluating the operation and maintenance manuals for both municipal wastewater treatment facilities, and for pumping station and/or pipelines. In addition, guidelines for estimating manual preparation costs are included.

6. Sopper, W.E. and L.T. Kardos, (ed.). Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland. University Park, Pennsylvania. The Pennsylvania State University Press. 1973.

The proceedings of a symposium co-sponsored by the Pennyslvania State University, the U.S. Department of Agriculture (Forest Service), and the Environmental Protection Agency, and held in 1972 are presented in this book. Thirty-two separate papers are included, with topics ranging from the fundamentals of soil treatment systems to research needs. Wastewater quality changes during recycling, and responses of the soil, vegetation, and other elements of the ecosystem are discussed. Examples of several operating and proposed systems are reported, and the status of guidelines for land disposal of wastewater are discussed.

7. Proceedings of Conference on Land Disposal of Municipal Effluents and Sludges. Rutgers University. March 1973.

Current research and studies on land application of municipal effluents and sludges are reported in nineteen separate papers. Overviews of land treatment are presented from the viewpoint of the Environmental Protection Agency, an environmentalist, and a state regulatory director. Topics relating to the current knowledge of wastewater characteristics, fate of materials applied, and public health effects are addressed. Preliminary results of Environmental Protection Agency research and state-of-the-art studies are also given.

8. Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land. Champaign, Illinois. July 1973.

This document includes information gathered at the Research Needs Workshop, sponsored by the ad-hoc subcommittee of EPA-USDA-Universities representatives. In addition to reports of the ten workshop sessions, twenty-four individual papers on aspects of soil treatment ranging from inorganic reactions in the soil to public acceptance of new systems are presented. Soil-plant relationships, and crop and food chain effects are described. Some of the capabilities of the Soil Conservation Service and the Agricultural Extension Service are outlined and some informal opinions on the outlook of the Food and Drug Administration are given.

9. Pair, C.H. (ed.). Sprinkler-Irrigation. 3rd Edition and Supplement. Silver Spring. Sprinkler Irrigation Association. 1969 and 1973.

In this book, all aspects of spray irrigation design from pumping plants to distribution systems are discussed. Besides crop irrigation, uses of sprinklers such as for environmental control (frost and heat control), fertilizer, and chemical applications, waste disposal, and fire protection are delineated. Soil-plant-water relations are explained with all current techniques for management of irrigation. Irrigation water requirements for many crops are included along with methods for determining water demands. The text is especially useful in the hydraulic design of sprinkler systems.

The supplement, published in 1973, consists of an additional four chapters including (1) turf irrigation, (2) continuously moving mechanical sprinkler systems, (3) land application of liquid wastes (good design advice), and (4) thermoplastic pipe.

10. Zimmerman, J. P. Irrigation. John Wiley & Sons, Inc. New York. 1966.

In this book, Zimmerman presents a comprehensive engineering approach to the design of irrigation systems. All aspects of the system are discussed, and a wide range of design elements is described for each of the irrigation methods (corrugation and furrow, border strip, sprinkling, flush flood spreading, and subirrigation). Other elements that are related to the system, such as reservoirs, canals, pumping, piping, and measuring devices, are also described.

11. Drainage of Agricultural Land. Soil Conservation Service, U. S. Department of Agriculture. Water Information Center, Inc. 1973.

This handbook, which was reproduced from the SCS National Engineering Handbook, presents a complete discussion of drainage principles as well as detailed descriptions of design features. Both surface and subsurface drainage are considered. In addition, sections on dikes, drainage pumping, drainage of organic soils, and drainage of tidal lands are included.

12. Chapman, H. D., (ed.). Diagnostic Criteria for Plants and Soils. Abilene, Quality Printing Company, Inc. 1965.

In this comprehensive reference, the effects of a large number of elements on plants and soils are described. Methods for diagnosing the existing status (deficiencies or toxic levels) and control provisions are described for each element. The effects of alkali and saline soils, and organic soil toxins are also considered. In addition, an extensive table is included, which shows levels of various elements (ranging from deficient to toxic levels) for a large number of plants.

13. Thomas, R. E. and C. C. Harlin, Jr. Experiences with Land Spreading of Municipal Effluents. First Annual IFAS Workshop on Land Renovation of Wastewater in Florida. Tampa, Florida. June 1972.

An overview of the use of land application as a treatment process is presented, in which the three major methods (infiltration-percolation, cropland irrigation, and spray-runoff) are defined. The general applicability and potential of each method are discussed, and Environmental Protection Agency-sponsored research projects are described.

14. Thomas, R.E. Spray-Runoff to Treat Raw Domestic Wastewater. International Conference on Land for Waste Management. Ottawa, Canada. October 1973.

Field studies conducted by the Environmental Protection Agency at Ada, Oklahoma, in which the capabilities of a spray-runoff (overland flow) system were evaluated, are described. During the 18-month study period, comminuted raw wastewater was applied to three experimental plots at varying loading rates. Results of the study are discussed, with removal efficiencies being reported for: COD, BOD, TOC, nitrogen, phosphorus, and suspended solids.

15. Bouwer, H., R.C. Rice, and E.D. Escarcega. Renovating Secondary Sewage by Ground Water Recharge with Infiltration Basins. Office of Research and Monitoring, Environmental Protection Agency. March 1972.

A five year infiltration-percolation demonstration project at Flushing Meadows, Arizona, is detailed in this report. The feasibility of renovating activated sludge effluent was studied using six parallel basins in loamy sand. The wide variety of application schedules that were tried are described in the report, and results of the groundwater analyses are given with respect to: suspended solids, BOD, fecal coliform, nitrogen, phosphorus, fluorides, boron, and heavy metals. Special emphasis is given to nitrogen removal.

16. Law, J.P., R.E. Thomas, and L.H. Myers. Cannery Wastewater Treatment by High-Rate Spray on Grassland. Journal WPCF, 42, No. 9, pp 1621-1631. 1970.

A one-year study of an industrial spray-runoff (overland flow) system in Paris, Texas, is described in this report. Four separate plots of varying slopes, lengths, soil conditions, and periods of operation were studied. Summaries of quality analyses are presented for the wastewater applied, system effluent, and soil water. Removal efficiencies are presented with respect to: BOD, COD, suspended solids, nitrogen, and phosphorus.

17. Kirby, C.F. Sewage Treatment Farms. Department of Civil Engineering. University of Melbourne. 1971.

In this paper, the three methods of treating wastewater from the City of Melbourne – land filtration, grass filtration, and lagooning – are discussed. The land filtration process consists of pasture irrigation with grazing by cattle and sheep. Grass filtration, known in the United States as overland flow, is notable because it is the only known full-scale system using municipal wastewater. Also of note is the fact that in this system wastewater is applied by flooding, as opposed to spraying, which is the only application method presently employed by U.S. industries. Loadings and removals of various wastewater constituents are included in the paper.

## Appendix C

## GLOSSARY OF TERMS, ABBREVIATIONS, SYMBOLS, AND CONVERSION FACTORS

### TERMS

Adsorption — A process in which soluble substances are attracted to and held at the surface of soil particles.

Aerosol — A suspension of fine solid or liquid particles in air or gas.

Alkali soil — A soil with a high degree of alkalinity (pH of 8.5 or higher) or with a high exchangeable sodium content (15 percent or more of the exchange capacity), or both.

Application rate — The rate at which a liquid is dosed to the land (in./hr, ft/yr, etc.).

Aquifer — A geologic formation or stratum that contains water and transmits it from one point to another in quantities sufficient to permit economic development.

Border strip method — Application of water over the surface of the soil. Water is applied at the upper end of the long, relatively narrow strip.

Conductivity — Quality or capability of transmitting and receiving. Normally used with respect to electrical conductivity (EC).

Consumptive use — Synonymous with evapotranspiration.

Contour check method — Surface application by flooding. Dikes constructed at contour intervals to hold the water.

Conventional wastewater treatment — Reduction of pollutant concentrations in wastewater by physical, chemical, or biological means.

Drainability — Ability of the soil system to accept and transmit water by infiltration and percolation.

Evapotranspiration — The unit amount of water used on a given area in transpiration, building of plant tissue, and evaporation from adjacent soil, snow, or intercepted precipitation in any specified time.

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Field area – Total area of treatment for a land-application system including the wetted area.

Fixation – A combination of physical and chemical mechanisms in the soil that act to retain wastewater constituents within the soil, including adsorption, chemical precipitation, and ion exchange.

Flooding – A method of surface application of water which includes border strip, contour check, and spreading methods.

Grass filtration – See overland flow.

Groundwater – The body of water that is retained in the saturated zone which tends to move by hydraulic gradient to lower levels.

Groundwater table – The free surface elevation of the groundwater; this level will rise and fall with additions or withdrawals.

Infiltration – The entrance of applied water into the soil through the soil-water interface.

Infiltration-percolation – An approach to land application in which large volumes of wastewater are applied to the land, infiltrate the surface, and percolate through the soil pores.

Irrigation – Application of water to the land to meet the growth needs of plants.

Land application – The discharge of wastewater onto the soil for treatment or reuse.

Lithology – The study of rocks; primarily mineral composition.

Loading rate – The average amount of liquid or solids applied to the land over a fixed time period, taking into account periodic resting.

Lysimeter – A device for measuring percolation and leaching losses from a column of soil. Also a device for collecting soil water in the field.

Micronutrient – A chemical element necessary in only small amounts (less than 1 mg/l) for microorganism and plant growth.

Mineralization – The conversion of an element from an organic form to an inorganic form as a result of microbial decomposition.

Overland flow – Wastewater treatment by spray-runoff (also known as "grass filtration" and "spray runoff") in which wastewater is sprayed onto gently sloping, relatively impermeable soil that has been planted to vegetation. Biological oxidation occurs as the wastewater flows over the ground and contacts the biota in the vegetative litter.

Pathogenic organisms – Microorganisms that can transmit diseases.

Percolation – The movement of water beneath the ground surface both vertically and horizontally, but above the groundwater table.

Permeability – The ability of a substance (soil) to allow appreciable movement of water through it when saturated and actuated by a hydrostatic pressure.

Phytotoxic – Toxic to plants.

Primary effluent – Wastewater that has been treated by screening and sedimentation.

Ridge and furrow method – The surface application of water to the land through formed furrows; wastewater flows down the furrows and plants may be grown on the ridges.

Saline soil – A nonalkali soil containing sufficient soluble salts to impair its productivity.

Secondary treatment – Treatment of wastewater which meets the standards set forth in 40 CFR 133.

Sewage farming – Originally involved the transporting of sewage to rural areas for land disposal. Later practice included reusing the water for irrigation and fertilization of crops.

Soil texture – The relative proportions of the various soil separates – sand, silt, and clay.

Soil water – That water present in the soil pores in an unsaturated zone above the groundwater table.

Spraying – Application of water to the land by means of stationary or moving sprinklers.

Spray-runoff – See overland flow.

Tilth – The physical condition of a soil as related to its ease of cultivation.

Transpiration – The net quantity of water absorbed through plant roots that is used directly in building plant tissue, or given off to the atmosphere.

Viruses – Submicroscopic biological structures containing all the information necessary for their own reproduction.

Wetted area – Area within the spray diameter of the sprinklers.

## ABBREVIATIONS

acre-ft – acre-foot

BOD – biochemical oxygen demand

BPT – best practicable treatment technology

cm – centimeter

COD – chemical oxygen demand

cu. m – cubic meter

deg C – degree Centigrade

deg F – degree Fahrenheit

EC – electrical conductivity

ECdw – maximum EC of drainage water permissible for plant growth

ECe – EC of saturation extract (from soil)

ECw – EC of irrigation water

ENRCC – *Engineering News-Record* construction cost (index)

FDA – Food and Drug Administration

fps – feet per second

ft – foot

gal. – gallon

gpm – gallons per minute

ha – hectare

hr – hour

in. – inch

kg – kilogram

l – liter

lb — pound
m — meter
max — maximum
mgd — million gallons per day
mg/l — milligrams per liter
min — minute
ml — milliliter
mm — millimeter
mmho/cm — millimhos per centimeter
MPN — most probable number
ppm — parts per million
psi — pounds per square inch
SAR — sodium adsorption ratio
SCS — Soil Conservation Service
sec — second
sq ft — square foot
SS — suspended solids
STPCC — sewage treatment plant construction cost (index)
TOC — total organic carbon
TDS — total dissolved solids
USDA — U.S. Department of Agriculture
USGS — U.S. Geological Survey
wk — week
yr — year

## SYMBOLS

B — boron
Ca — calcium
Cu — copper
K — potassium
Fe — iron
Mg — magnesium
Mn — manganese
N — nitrogen
Na — sodium
$NH_3$ — ammonia
$NO_3$ — nitrate
P — phosphorus
S — sulfur
Zn — zinc
$>$ — greater than
$<$ — less than
$\mu$ — micro

## CONVERSION FACTORS

million gallons x 3.06 = acre-feet
acre-inch x 27,154 = gallons
mg/l x ft/yr x 2.7 = lb/acre/yr
mgd x 43.814 = l/s
million gallons x 3785 = cu. m

acre x 0.4047 = ha

acre-feet x 1234 = cu. m

lb/acre x 1.121 = kg/ha

inch x 2.540 = cm

ft x 30.48 = cm

# Appendix D

# TYPICAL SUMMARY OF DESIGN CRITERIA FOR LAND-APPLICATION SYSTEMS

## Table D-1. IRRIGATION

| | Unit[a] | | |
|---|---|---|---|
| Item | English | Metric | Value |
| Flow | | | |
| Design flow, avg annual | mgd | l/s | ——— |
| Design peak flow | mgd | l/s | ——— |
| Field area | acres | hectares | ——— |
| Water balance | | | |
| Design total annual precipitation[b] | in./yr | cm/yr | ——— |
| Return period | yr | yr | ——— |
| Design evapotranspiration | in./yr | cm/yr | ——— |
| Design percolation rate | in./yr | cm/yr | ——— |
| Effluent application rate[c] | in./yr | cm/yr | ——— |
| Nitrogen (as N) loading rate[c] | lb/acre/yr | kg/ha/yr | ——— |
| Other constituent loading rate[c] | lb/acre/yr | kg/ha/yr | ——— |
| Effluent water quality | | | |
| TDS | mg/l | mg/l | ——— |
| Sodium adsorption ratio | SAR | SAR | ——— |
| Application rates | | | |
| Length of operating season | wk/yr | wk/yr | ——— |
| Hourly rate (spray application) | in./hr | cm/hr | ——— |
| Application period | hr | hr | ——— |
| Application cycle[d] | day | day | ——— |
| Avg weekly rate | in./wk | cm/wk | ——— |
| Max weekly rate[e] | in./wk | cm/wk | ——— |
| Storage capacity | mg | cu m | ——— |
| Rate of recovery of renovated water | mgd | l/s | ——— |

a. Typical units are given with a choice between English and Metric systems.

b. When design values of different return periods are used for determining liquid loading rates and storage capacities, both values should be shown.

c. If critical, indicate with an asterisk.

d. Combination of one application period and one drying period.

e. Includes additional flow from storage withdrawal.

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## Table D-2. INFILTRATION-PERCOLATION

| Item | Unit[a] English | Unit[a] Metric | Value |
|---|---|---|---|
| **Flow** | | | |
| Design flow, avg annual | mgd | l/s | ____ |
| Design peak flow | mgd | l/s | ____ |
| Field area | acres | hectares | ____ |
| **Water balance** | | | |
| Design total annual precipitation[b] | in./yr | cm/yr | ____ |
| Return period | yr | yr | ____ |
| Design evapotranspiration | in./yr | cm/yr | ____ |
| Design percolation rate | in./yr | cm/yr | ____ |
| Effluent application rate[c] | in./yr | cm/yr | ____ |
| Design runoff rate | in./yr | cm/yr | ____ |
| Organic (BOD) loading rate[c] | lb/acre/yr | kg/ha/yr | ____ |
| Nitrogen (as N) loading rate[c] | lb/acre/yr | kg/ha/yr | ____ |
| Phosphorus loading rate[c] | lb/acre/yr | kg/ha/yr | ____ |
| Other constituent loading rate[c] | lb/acre/yr | kg/ha/yr | ____ |
| **Application rates** | | | |
| Length of operating season | wk/yr | wk/yr | ____ |
| Avg weekly rate | in./wk | cm/wk | ____ |
| Max weekly rate | in./wk | cm/wk | ____ |
| Application period | hr | hr | ____ |
| Resting period | hr | hr | ____ |
| Storage | mg | cu m | ____ |
| Rate or recovery of renovated water | mgd | l/s | ____ |

a. Typical units are given with a choice between English and Metric systems.

b. When design values of different return periods are used for determining liquid loading rates and storage capacities, both values should be shown.

c. If critical, indicate with an asterisk.

## Table D-3. OVERLAND FLOW

| | Unit[a] | | |
|---|---|---|---|
| Item | English | Metric | Value |
| **Flow** | | | |
| Design flow, avg annual | mgd | l/s | ____ |
| Design peak flow | mgd | l/s | ____ |
| **Field area** | | | |
| No. of basins or plots | | | |
| Total area | acres | hectares | ____ |
| **Water balance** | | | ____ |
| Design total annual precipitation[b] | in./yr | cm/yr | ____ |
| Return period | yr | yr | ____ |
| Design evapotranspiration | in./yr | cm/yr | ____ |
| Design percolation rate | ft/yr | m/yr | ____ |
| Effluent application rate[c] | ft/yr | m/yr | ____ |
| **Organic (BOD) loading rate[c]** | lb/acre/yr | kg/ha/yr | ____ |
| **Nitrogen (as N) loading rate[c]** | lb/acre/yr | kg/ha/yr | ____ |
| **Phosphorus loading rate[c]** | lb/acre/yr | kg/ha/yr | ____ |
| **Other constituent loading rate[c]** | lb/acre/yr | kg/ha/yr | ____ |
| **Application rates** | | | |
| Length of operating season | wk/yr | wk/yr | ____ |
| Application period[d] | day | day | ____ |
| Rate[d] | in./day | cm/day | ____ |
| Drying or resting period | day | day | ____ |
| **Storage capacity** | mg | cu m | ____ |
| **Rate of recovery of renovated water** | mgd | l/s | ____ |

[a] Typical units are given with a choice between English and Metric systems.

[b] When design values of different return periods are used for determining liquid loading rates and storage capacities, both values should be shown.

[c] Indicate critical loading rate by means of asterisk.

[d] Include ranges of periods and rates if significant seasonal variations exist.

## Appendix E

## PROPOSED CALIFORNIA REGULATIONS

The following is a set of regulations that has been proposed to replace existing California regulations. It is offered only as an example.

### STATEWIDE RECLAMATION CRITERIA FOR USE OF RECLAIMED WATER FOR IRRIGATION AND RECREATIONAL IMPOUNDMENTS

California Administrative Code, Title 17, Chapter 5, Subchapter 1, Group 12

### Article 1. Definitions

8025. Definitions. (a) Reclaimed Water. Reclaimed water means water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur.

(b) Reclamation Plant. Reclamation plant means an arrangement of devices, structures, equipment, processes and controls which produce a reclaimed water suitable for the intended reuse.

(c) Regulatory Agency. Regulatory agency means the California Regional Water Quality Control Board in whose jurisdication the reclamation plant is located.

(d) Direct Beneficial Use. Direct beneficial use means the use of reclaimed water which has been transported from the point of production to the point of use without an intervening discharge to waters of the State.

(e) Food Crops. Food crops mean any crops intended for human consumption.

(f) Spray Irrigation. Spray irrigation means application of reclaimed water to crops by spraying it from orifices in piping.

(g) Surface Irrigation. Surface irrigation means application of reclaimed water by means other than spraying such that contact between the edible portion of any food crop and reclaimed water is prevented.

(h) Restricted Recreational Impoundment. A restricted recreational impoundment is a body of reclaimed water in which recreation is limited to fishing, boating, and other non-body-contact water recreation activities.

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(i) Non-Restricted Recreational Impoundment. A non-restricted recreational impoundment is an impoundment of reclaimed water in which no limitations are imposed on body-contact water sport activities.

(j) Landscape Impoundment. A landscape impoundment is a body of reclaimed water which is used for aesthetic enjoyment or which otherwise serves a function intended to exclude public contact.

(k) Approved Laboratory Methods. Approved laboratory methods are those specified in the latest edition of "Standard Methods for the Examination of Water and Wastewater," prepared and published jointly by the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation, and which are conducted in laboratories approved by the State Department of Health.

(l) Unit Process. Unit process means an individual stage in the wastewater treatment sequence which performs a major single operation.

(m) Primary Effluent. Primary effluent is the effluent from a sewage treatment process which provides partial removal of sewage solids by physical methods so that it contains not more than 0.5 milliliter per liter per hour of settleable solids as determined by an approved laboratory method.

(n) Oxidized Wastewater. Oxidized wastewater means wastewater in which the organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen.

(o) Biological Treatment. Biological treatment means methods of wastewater treatment in which bacterial or biochemical action is intensified as a means of producing an oxidized wastewater as defined in (n).

(p) Secondary Sedimentation. Secondary sedimentation means the removal by gravity of settleable solids remaining in the effluent after the biological treatment process.

(q) Coagulated Wastewater. Coagulated wastewater means oxidized wastewater in which colloidal and finely divided suspended matter has been destabilized and agglomerated by the addition of suitable floc-forming chemicals or by an equally effective method.

(r) Filtered Wastewater. Filtered wastewater means an oxidized coagulated wastewater which has been passed through natural undisturbed soils or filter media, such as sand or diatomaceous earth, so that the turbidity as determined by an approved laboratory method does not exceed an average operating turbidity of 2 turbidity units and does not exceed 5 turbidity units more than 5 percent of the time during any 24-hour period.

(s) Disinfected Wastewater. Disinfected wastewater means wastewater in which the pathogenic organisms have been destroyed by chemical, physical, or biological means.

(t) Multiple Units. Multiple units mean two or more units of a treatment process which operate in parallel and serve the same function.

(u) Standby Unit Process. A standby unit process is an alternate unit process which is maintained in operable condition and which is capable of providing comparable treatment for the entire design flow in the event that the unit for which it is a substitute becomes inoperative.

(v) Power Source. Power source means a source of supplying energy to operate unit processes.

(w) Standby Power Source. Standby power source means an alternate energy source such as an engine driven generator, maintained in immediately operable condition and of sufficient capacity to provide necessary service during failure of the normal power supply.

(x) Alarm. Alarm means an instrument or device which continuously monitors a specific function of a treatment process and automatically gives warning of an unsafe or undesirable condition by means of visual and audible signals.

(y) Person. Person also includes any city, county, district, the State or any department or agency thereof.

## Article 2. Irrigation of Food Crops

8030. Spray Irrigation. Reclaimed water used for the spray irrigation of food crops shall be at all times an adequately disinfected, oxidized, coagulated, filtered wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 2.2 per 100 milliliters and the number of coliform organisms in any sample does not exceed 23 per 100 milliliters. The median value shall be determined from the bacteriological results of the last 7 days for which analyses have been completed.

8031. Surface Irrigation. (a) Reclaimed water used for surface irrigation of food crops shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 2.2 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

(b) Orchards and vineyards may be surface irrigated with reclaimed water that has the quality at least equivalent to that of primary effluent provided that no fruit is harvested that has come in contact with the irrigating water or the ground.

8032. Exceptions. Exceptions to the quality requirements for reclaimed water used for irrigation of food crops may be considered by the State Department of Health on an individual case basis where the reclaimed water is to be used to irrigate a food crop which must undergo extensive commercial, physical, or chemical processing sufficient to destroy pathogenic agents before it is suitable for human consumption.

## Article 3. Irrigation of Fodder, Fiber, and Seed Crops

8035. Fodder, Fiber, and Seed Crops. Reclaimed water used for the surface or spray irrigation of fodder, fiber, and seed crops shall have a level of quality no less than that of primary effluent.

8036. Pasture for Milking Animals. Reclaimed water used for the irrigation of pasture to which milking cows or goats have access shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 23 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

## Article 4. Landscape Irrigation

8039. Landscape Irrigation. Reclaimed water used for the irrigation of golf courses, cemeteries, lawns, parks, playgrounds, freeway landscapes, and landscapes in other areas where the public has access shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 23 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

## Article 5. Recreational Impoundments

8042. Non-Restricted Recreational Impoundment. Reclaimed water used as a source of supply in a non-restricted recreational impoundment shall be at all times an adequately disinfected, oxidized, coagulated, filtered wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed

2.2 per 100 milliliters and the number of coliform organisms in any sample does not exceed 23 per 100 milliliters. The median value shall be determined from the bacteriological results of the last 7 days for which analyses have been completed.

8043. Restricted Recreational Impoundment. Reclaimed water used as a source of supply in a restricted recreational impoundment shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 2.2 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

8044. Landscape Impoundment. Reclaimed water used as a source of supply in a landscape impoundment shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 23 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

## Article 6. Sampling and Analysis

8047. Sampling and Analysis. (a) Samples for settleable solids and coliform bacteria, where required, shall be collected at least daily and at a time when wastewater characteristics (highest organic and hydraulic mass loading) are most demanding on the treatment facilities and disinfection procedures. Turbidity analysis, where required, shall be performed by a continuous recording turbidimeter.

(b) For uses requiring a level of quality no less than that of primary effluent, samples shall be analyzed by an approved laboratory method for settleable solids.

(c) For uses requiring an adequately disinfected, oxidized wastewater, samples shall be analyzed by an approved laboratory method for coliform bacteria content.

(d) For uses requiring an adequately disinfected, oxidized, coagulated, filtered wastewater, samples shall be analyzed by approved laboratory methods for turbidity and coliform bacteria content.

## Article 7. Engineering Report and Operational Requirements

8050. Engineering Report. (a) No person shall produce or supply reclaimed water as defined in Section 13050 (n) of the Water Code for direct reuse from a proposed water reclamation plant unless he files an engineering report in accordance with Water Code Section 13522.5.

(b) The report shall be prepared by a civil engineer registered in California and experienced in the field of wastewater treatment, and shall contain a description of the design of the proposed reclamation system. The report shall clearly indicate the means for compliance with these regulations and any other features specified by the regulatory agency.

8051. Personnel. (a) Each reclamation plant shall be provided with sufficient number of qualified personnel to operate the facility effectively so as to achieve the required level of treatment at all times.

(b) Qualified personnel shall be those meeting requirements established pursuant to Chapter 9 (commencing with Section 13625) of the Water Code.

8052. Maintenance. An equipment maintenance program shall be provided at each reclamation plant to ensure that all equipment is kept in a highly reliable operating condition.

8053. Operational Records and Reports. (a) Operating records shall be maintained at the reclamation plant or a centralized depository within the operating agency. These shall include all analyses specified in the reclamation criteria and records of operational problems, plant and equipment breakdowns, diversions to emergency storage or disposal, and all corrective or preventive action taken.

(b) Process or equipment failures triggering an alarm shall be recorded and maintained as a separate record file. The recorded information shall include the time and cause of failure and corrective action taken.

(c) A monthly summary of operating records as specified under (a) and (b) in this section shall be filed monthly with the regulatory agency.

(d) Any discharge of untreated or partially treated wastewater to the use area, and the cessation of same, shall be reported by telephone to the regulatory agency, the State Department of Health, and the local health officer.

8054. Bypass. There shall be no bypassing of untreated or partially treated wastewater from the reclamation plant or any intermediate unit processes to the point of use.

## Article 8. General Requirements of Design

8057. Flexibility of Design. The design of process piping, equipment arrangement, and unit structures in the reclamation plant must allow for efficiency and convenience in operation and maintenance and provide flexibility of operation to permit the highest possible degree of treatment to be obtained under varying circumstances.

8058. Alarms. (a) Alarm devices required for various unit processes as specified in other sections of these regulations shall be installed to provide warning of at least the following process failures:

(1) Loss of power from normal power supply.

(2) Loss of air supply or any other event which may result in failure of a biological treatment process.

(3) Loss of chlorine supply, low chlorine residual, failure of injector water supply, and any other event which may result in failure of a disinfection process.

(4) Loss of coagulant feed and any other event which may result in failure of a coagulation process.

(5) Excessive headloss, excessive turbidity, and any other event or parameter which may result in failure of a filtration process.

(6) Any other specific process failure for which warning is required by the regulatory agency.

(b) All required alarm devices shall be independent of the main power supply of the reclamation plant.

(c) The person to be warned shall be the plant operator, superintendent, or any other responsible person designated by the management of the reclamation plant and capable of taking prompt corrective action.

(d) Individual alarm devices may be connected to a master alarm to sound at a location where it can be conveniently observed by the attendant. In case the reclamation plant is not attended full time, alarm(s) shall be connected to sound at a police station, fire station or other full time service unit with which arrangements have been made to alert the person in charge at times that the reclamation plant is unattended.

8059. Power Supply. Provisions shall be made for substitute power in the event of failure of the normal power supply including one of the following reliability features:

(a) Alarm and standby power source, including automatic switchover to self-starting standby power source if the plant will not be attended continuously.

(b) Alarm and automatically actuated short-term retention provisions for untreated wastewater as specified in Section 8064.

(c) Automatically actuated long-term emergency storage or disposal provisions for untreated wastewater as specified in Section 8064.

### Article 9. Alternative Reliability Requirements for Uses Permitting Primary Effluent

8061. Primary Treatment. Reclamation plants producing reclaimed water exclusively for uses for which primary effluent is permitted shall be provided with one of the following reliability features:

(a) Multiple or standby primary treatment units, as specified in Section 8064, capable of providing essentially unimpaired treatment when one unit is taken out of service.

(b) Long-term emergency storage or disposal provisions as specified in Section 8064.

### Article 10. Alternative Reliability Requirements for Uses Requiring Oxidized, Disinfected Wastewater or Oxidized, Coagulated, Filtered, Disinfected Wastewater

8064. Definitions Relating to Reliability Requirements. (a) Multiple biological treatment units mean multiple tanks and multiple units of all critical process equipment such as blowers, aerators, and recirculation pumps.

(b) Standby replacement equipment means reserve parts and equipment such as pumps, valves, controls, and instruments to replace broken-down or worn-out units which can be assembled and placed in operation within a 24-hour period.

(c) Uninterrupted coagulant feed means all of the following mandatory features: standby feeders, adequate chemical storage and conveyance facilities, adequate reserve chemical supply, automatic dosage control, and alarms to warn of equipment breakdown.

(d) Uninterrupted chlorine feed means the following mandatory features: standby chlorine supply, manifold systems to connect chlorine cylinder scales; alarms to warn of malfunctions, automatic devices for switching over to full chlorine cylinders, and in addition may require automatic residual control of chlorine dosage, automatic measuring and recording of chlorine residual, and hydraulic performance studies.

(e) A standby chlorinator means a duplicate chlorinator for reclamation plants having one chlorinator; duplicate of the largest unit for plants having multiple chlorinator units. All standby equipment shall be maintained in immediate operable condition.

(f) Multiple point chlorination means that chlorine will be applied simultaneously at the reclamation plant and at subsequent chlorination stations located at the use area and/or some intermediate point. It does not include chlorine application for odor control purposes.

(g) Where short-term retention is provided as a reliability feature, it shall consist of facilities reserved for the purpose of storing or disposing of untreated or partially treated wastewater for at least a 24-hour period. The facilities shall include all the necessary diversion devices, provisions for odor control, conduits and pumping and pump back equipment, and shall be either independent of normal power or provided with a standby power source.

(h) Where long-term emergency storage or disposal provisions are used as a reliability feature, these shall consist of ponds, reservoirs, percolation areas, downstream sewers leading to other treatment or disposal facilities or any other facilities reserved for the purpose of emergency storage or disposal of untreated or partially treated wastewater. These facilities shall be of sufficient capacity to provide disposal or storage of wastewater for at least 20 days, and shall include all the necessary diversion works, provisions for odor and nuisance control, conduits and pumping and pump back equipment. The emergency equipment shall be either independent of normal power or provided with a standby power source.

(1) Diversion to a less demanding reuse is an acceptable alternative to emergency disposal of partially treated wastewater provided that the quality of the partially treated wastewater is suitable for the less demanding reuse.

(2) Subject to prior approval by the regulatory agency, diversion to a discharge point which requires lesser quality of wastewater is an acceptable alternative to emergency disposal of partially treated wastewater.

(3) Automatically actuated long-term emergency storage or disposal provisions shall include, in addition to provisions of part (h) of this section, or parts (1) or (2) of this subsection, all the necessary sensors, instruments, valves and other devices to enable fully automatic diversion of untreated or partially treated wastewater to approved emergency storage or disposal in the event of failure of a treatment process, and a manual reset to prevent automatic restart until the failure is corrected.

(i) Multiple or standby primary treatment units mean multiple or standby tanks and multiple or standby units of all critical process equipment such as sludge transfer facilities.

8065. Primary Effluent. All primary treatment unit processes shall be provided with one of the following reliability features:

(a) Multiple units to enable partial treatment of wastewater with one unit not in operation.

(b) Standby primary treatment unit process.

(c) Long-term emergency storage or disposal provisions.

8066. Biological Treatment. All biological treatment unit processes shall be provided with one of the following reliability features:

(a) Alarm and multiple biological treatment units capable of producing oxidized wastewater with one unit not in operation.

(b) Alarm, short-term retention provisions, and standby replacement equipment.

(c) Alarm and long-term emergency storage or disposal provisions.

(d) Automatically actuated long-term emergency storage or disposal provisions.

8067. Secondary Sedimentation. All secondary sedimentation unit processes shall be provided with one of the following reliability features:

(a) Multiple sedimentation units capable of providing essentially unimpaired treatment when one unit is taken out of service.

(b) Standby sedimentation unit process.

(c) Long-term emergency storage or disposal provisions.

8068. Coagulation. All coagulation unit processes shall be provided with special provisions for uninterrupted coagulant feed and one of the following reliability features:

(a) Alarm and multiple coagulation units capable of treating the entire flow with one unit not in operation.

(b) Alarm, short-term retention provisions and standby replacement equipment.

(c) Alarm and long-term emergency storage or disposal provisions.

(d) Automatically actuated long-term emergency storage or disposal provisions.

(e) Alarm and standby coagulation unit process.

8069. Filtration. All filtration unit processes shall be provided with one of the following reliability features:

(a) Alarm and multiple filter units capable of treating the entire flow with one unit not in operation.

(b) Alarm, short-term retention provisions and standby replacement equipment.

(c) Alarm and long-term emergency storage or disposal provisions.

(d) Automatically actuated long-term emergency storage or disposal provisions.

(e) Alarm and standby filtration unit process.

8070. Disinfection. All disinfection unit processes where chlorine is used as the disinfectant shall be provided with features for uninterrupted chlorine feed and one of the following reliability features:

(a) Alarm and standby chlorinator.

(b) Alarm, short-term retention provisions and standby replacement equipment.

(c) Alarm and long-term emergency storage or disposal provisions.

(d) Automatically actuated long-term emergency storage or disposal provisions.

(e) Alarm and multiple point chlorination, each with independent power source, separate chlorinator, and separate chlorine supply.

8071. Other Alternatives to Reliability Requirements. Other alternatives to reliability requirements set forth in Articles 8 to 10 may be accepted if the applicant demonstrates to the satisfaction of the regulatory agency that the proposed alternative will assure an equal degree of reliability.

## Article 11. Other Methods of Treatment

8072. Other Methods of Treatment. Methods of treatment other than those included in this chapter and their reliability features will be evaluated by the regulatory agency on a case-by-case basis.

## Appendix F

## SOURCES OF DATA

To assist the evaluator and engineer in data-gathering and evaluation, some major sources of data are listed for climate, topography, soil characteristics, geologic formations, groundwater, and receiving water. It must be stressed that these do not represent all the possible sources of data.

### CLIMATE

Information on precipitation, temperature, humidity, and winds may be obtained from the following sources:

- National Weather Service, local offices
- Climatological Data, published by the National Weather Service, Department of Commerce
- Airports
- Universities
- Military installations

The National Oceanographic and Atmospheric Administration is preparing a report for EPA on weather parameters that influence winter operations of land-application systems. This report, when available in early 1975, should be an excellent source of climatological data.

Additionally, data on evapotranspiration can usually be obtained from the following sources:

- Agricultural Extension Service
- Agricultural Experiment Stations
- Agencies managing large water reservoirs

### TOPOGRAPHY

Topographic maps and aerial photographs can provide much of the information needed to analyze the topography. Topographic maps are most widely available from the U.S. Geological Survey in 7.5- and 15-minute quadrangles. Aerial photographs, when they exist, may be located by contacting the following sources:

- U.S. Department of Agriculture, Commodity Stabilization program
- Local or county planning departments
- U.S. Corps of Engineers offices
- Private photogrammetry and mapping companies

## SOIL CHARACTERISTICS

Consultation with the Soil Conservation Service (U.S. Department of Agriculture) to obtain information on soil characteristics is highly recommended. SCS offices exist in most counties; however, each county office does not necessarily have a soil scientist. The state soil scientists should therefore be contacted. Additionally, SCS has published many soil maps with descriptions of soil characteristics to a depth of 5 feet. These descriptions include groundslopes, existing land use, erosion potential, and surface drainage, which are also important considerations. Agricultural Extension Service representatives, consulting soil scientists, or agronomists may have additional information on soil characteristics.

## GEOLOGIC FORMATIONS

The U.S. Geological Service is the primary source of data on geological formations. Geologic maps and investigative reports are available for many areas. State mine and geology agencies may also have information on geologic formations in terms of maps or reports.

## GROUNDWATER

Data on groundwater may come from a number of different sources, such as state water resource agencies, the U.S. Geological Service, local or county water conservation districts, and users of groundwater (municipalities, water companies, and individuals).

## RECEIVING WATER

The U.S. Geological Service has monitoring gages on most large streams and many small ones. In addition to this flow data, data on temperature and mineral quality are collected. The EPA has a computer storage system (called STORET) that contains a great deal of water-quality data from one-time studies and continuous monitoring by federal, state, and local agencies. STORET output can be obtained at Regional EPA offices.

# Appendix G

# COST-EFFECTIVENESS ANALYSIS GUIDELINES
## (40 CFR 35 - Appendix A)

### Title 40—Protection of the Environment

### CHAPTER I—ENVIRONMENTAL PROTECTION AGENCY

### SUBCHAPTER D—GRANTS

### PART 35—STATE AND LOCAL ASSISTANCE

### Appendix A—Cost-Effectiveness Analysis

On July 3, 1973, notice was published in the FEDERAL REGISTER that the Environmental Protection Agency was proposing guidelines on cost-effectiveness analysis pursuant to section 212(2)(c) of the Federal Water Pollution Act Amendments of 1972 (the Act) to be published as appendix A to 40 CFR part 35.

Written comments on the proposed rulemaking were invited and received from interested parties. The Environmental Protection Agency has carefully considered all comments received. No changes were made in the guidelines as earlier proposed. All written comments are on file with the agency.

*Effective date.*—These regulations shall become effective October 10, 1973.

Dated September 4, 1973.

JOHN QUARLES,
*Acting Administrator.*

### APPENDIX A

### COST EFFECTIVENESS ANALYSIS GUIDELINES

a. *Purpose.*—These guidelines provide a basic methodology for determining the most cost-effective waste treatment management system or the most cost-effective component part of any waste treatment management system.

b. *Authority.*—The guidelines contained herein are provided pursuant to section 212 (2)(C) of the Federal Water Pollution Control Act Amendments of 1972 (the Act).

c. *Applicability.*—These guidelines apply to the development of plans for and the selection of component parts of a waste treatment management system for which a Federal grant is awarded under 40 CFR, Part 35.

d. *Definitions.*—Definitions of terms used in these guidelines are as follows:

(1) *Waste treatment management system.*—A system used to restore the integrity of the Nation's waters. Waste treatment management system is used synonymously with "treatment works" as defined in 40 CFR, Part 35.905-15.

(2) *Cost-effectiveness analysis.*—An analysis performed to determine which waste treatment management system or component part thereof will result in the minimum total resources costs over time to meet the Federal, State or local requirements.

(3) *Planning period.*—The period over which a waste treatment management system is evaluated for cost-effectiveness. The planning period commences with the initial operation of the system.

(4) *Service life.*—The period of time during which a component of a waste treatment management system will be capable of performing a function.

(5) *Useful life.*—The period of time during which a component of a waste treatment management system will be required to perform a function which is necessary to the system's operation.

e. *Identification, selection and screening of alternatives*—(1) *Identification of alternatives.*—All feasible alternative waste management systems shall be initially identified. These alternatives should include systems discharging to receiving waters, systems using land or subsurface disposal techniques, and systems employing the reuse of wastewater. In identifying alternatives, the possibility of staged development of the system shall be considered.

(2) *Screening of alternatives.*—The identified alternatives shall be systematically screened to define those capable of meeting the applicable Federal, State, and local criteria.

(3) *Selection of alternatives.*—The screened alternatives shall be initially analyzed to determine which systems have cost-effective potential and which should be fully evaluated according to the cost-effectiveness analysis procedures established in these guidelines.

(4) *Extent of effort.*—The extent of effort and the level of sophistication used in the cost-effectiveness analysis should reflect the size and importance of the project.

f. *Cost-Effective analysis procedures*—(1) *Method of Analysis.*—The resources costs shall be evaluated through the use of opportunity costs. For those resources that can be expressed in monetary terms, the interest (discount) rate established in section (f)(5) will be used. Monetary costs shall be calculated in terms of present worth values or equivalent annual values over the planning period as defined in section (f)(2). Nonmonetary factors (e.g., social and environmental) shall be accounted for descriptively in the analysis in order to determine their significance and impact.

The most cost-effective alternative shall be the waste treatment management system determined from the analysis to have the lowest present worth and/or equivalent annual value without overriding adverse nonmonetary costs and to realize at least identical minimum benefits in terms of applicable Federal, State, and local standards for effluent quality, water quality, water reuse and/or land and subsurface disposal.

(2) *Planning period.*—The planning period for the cost-effectiveness analysis shall be 20 years.

(3) *Elements of cost.*—The costs to be considered shall include the total values of the resources attributable to the waste treatment management system or to one of its component parts. To determine these values, all monies necessary for capital construction costs and operation and maintenance costs shall be identified.

Capital construction costs used in a cost-effectiveness analysis shall include all contractors' costs of construction including overhead and profit; costs of land, relocation, and right-of-way and easement acquisition; design engineering, field exploration, and engineering services during construction; administrative and legal services including costs of bond sales; startup costs such as operator training; and interest during construction. Contingency allowances consistent with the level of complexity and detail of the cost estimates shall be included.

Annual costs for operation and maintenance (including routine replacement of equipment and equipment parts) shall be included in the cost-effectiveness analysis. These costs shall be adequate to ensure effective and dependable operation during the planning period for the system. Annual costs shall be divided between fixed annual costs and costs which would be dependent on the annual quantity of wastewater collected and treated.

(4) *Prices.*—The various components of cost shall be calculated on the basis of market prices prevailing at the time of the cost-effectiveness analysis. Inflation of wages and prices shall not be considered in the analysis. The implied assumption is that all prices involved will tend to change over time by approximately the same percentage. Thus, the results of the cost effectiveness analysis will not be affected by changes in the general level of prices.

Exceptions to the foregoing can be made if their is justification for expecting significant changes in the relative prices of certain items during the planning period. If such cases are identified, the expected change in these prices should be made to reflect their future relative deviation from the general price level.

(5) *Interest (discount) rate.*—A rate of 7 percent per year will be used for the cost-effectiveness analysis until the promulgation of the Water Resources Council's "Proposed Principles and Standards for Planning Water and Related Land Resources." After promulgation of the above regulation, the rate established for water resource projects shall be used for the cost-effectiveness analysis.

(6) *Interest during construction.*—In cases where capital expenditures can be expected to be fairly uniform during the construction period, interest during construction may be calculated as $I \times \frac{1}{2} P \times C$ where:

$I$ = the interest (discount) rate in Section f(5).
$P$ = the construction period in years.
$C$ = the total capital expenditures.

In cases when expenditures will not be uniform, or when the construction period will be greater than three years, interest during construction shall be calculated on a year-by-year basis.

(7) *Service life.*—The service life of treatment works for a cost-effectiveness analysis shall be as follows:

| | |
|---|---|
| Land | Permanent |
| Structures (includes plant buildings, concrete process tankage, basins, etc.; sewage collection and conveyance pipelines; lift station structures; tunnels; outfalls) | 30–50 years |
| Process equipment (includes major process equipment such as clarifier mechanism, vacuum filters, etc.; steel process tankage and chemical storage facilities; electrical generating facilities on standby service only). | 15–30 years |
| Auxiliary equipment (includes instruments and control facilities; sewage pumps and electric motors; mechanical equipment such as compressors, aeration systems, centrifuges, chlorinators, etc.; electrical generating facilities on regular service). | 10–15 years |

Other service life periods will be acceptable when sufficient justification can be provided.

Where a system or a component is for interim service and the anticipated useful life is less than the service life, the useful life shall be substituted for the service life of the facility in the analysis.

(8) *Salvage value.*—Land for treatment works, including land used as part of the treatment process or for ultimate disposal of residues, shall be assumed to have a salvage value at the end of the planning period equal to its prevailing market value at the time of the analysis. Right-of-way easements shall be considered to have a salvage value not greater than the prevailing market value at the time of the analysis.

Structures will be assumed to have a salvage value if there is a use for such structures at the end of the planning period. In this case, salvage value shall be estimated using straightline depreciation during the service life of the treatment works.

For phased additions of process equipment and auxiliary equipment, salvage value at the end of the planning period may be estimated under the same conditions and on the same basis as described above for structures.

When the anticipated useful life of a facility is less than 20 years (for analysis of interim facilities), salvage value can be claimed for equipment where it can be clearly demonstrated that a specific market or reuse opportunity will exist.

[FR Doc.73-19104 Filed 9-7-73;8:45 am]

☆ U.S. Government Printing Office: 1976-678-279/337 Region 8